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# FUELS DESCRIPTION IN LODGEPOLE PINE STANDS OF THE COLORADO FRONT RANGE

BY

MARTIN E. ALEXANDER

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THESIS

# FUELS DESCRIPTION IN LODGEPOLE PINE STANDS OF THE COLORADO FRONT RANGE

Submitted by

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In partial fulfillment of the requirements

for the Degree of Master of Science

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY MARTIN E. ALEXANDER ENTITLED FUELS DESCRIPTION IN LODGEPOLE PINE STANDS OF THE COLORADO FRONT RANGE BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT OF THESIS

FUELS DESCRIPTION IN LODGEPOLE PINE STANDS OF THE COLORADO FRONT RANGE

Description of forest fuel complexes is essential to understanding and managing eastern Colorado Front Range lodgepole pine ecosystems in the presence and absence of fire. Ground and surface fuels data is virtually non-existent. Fuel inventories are limited by time and expense.

The purpose of the study reported here was to develop fuel prediction models for even-aged lodgepole pine stands utilizing stand and site characteristics as independent variables. Secondary objectives included fuel characterization by stylized stand types and vegetation classification units, acquisition of basic fuel inventory data, and development of equations for estimating fuel weights of two common shrubs from easily identifiable plant descriptors. The influence of lodgepole pine dwarf mistletoe parasitism effects on the fuel complex was also investigated.

Lodgepole pine fire ecology and effects, and fuel complex production, decomposition and accumulation dynamics are reviewed. Measurement and prediction studies of fuel complex strata and components in western North American lodgepole pine forests are summarized.

Stand structure, site, and fuel characteristics were measured in 28 fire-origin stands ranging in age from 57 to 282 years. Stands were sampled from 8,300 to 9,950 feet in elevation with seventy-five percent on northerly exposures. A fuel photo series was developed from these data.

Surface fuels less than three inches in diameter averaged 6.038 tons per acre with downed woody residues making up 74 percent of the total. Large downed fuel pieces three inches and greater in diameter averaged 6.623 tons per acre with rotten debris comprising 84 percent by weight.

Mean dead and live fuel, and duff depths were 2.71, 1.79, and 1.66 inches, respectively.

A significant difference in mean fuel descriptors between sapling and pole/sawtimber stands was not universal. Vegetation classification appears to be of value in characterizing understory vegetation fuels.

One and two independent variable regressions of ground, surface, and aerial fuel characteristics accounted for 31 to 87 percent of the total variation. In many cases, stand history hindered development and improvement of regressions. Dead woody surface fuels were most closely related to dead stem stand characteristics whereas live fuel descriptors correlated best with live stem stand attributes. Predicted values compared against literature data were generally within the expected range of variation.

Regressions for estimating kinnikinnick and whortleberry fuel weights from shrub height and/or percent cover accounted for 82 and 61 percent of the total variation, respectively.

No consistent, significant difference was apparent for surface fuel characteristics in more heavily infested dwarf mistletoe stands. The primary effect of dwarf mistletoe parasitism on the fuel complex was the greater potential for crown fire development.

Study results should have interim application to several fuel and fire management program activities in eastern Colorado Front Range lodgepole pine forests. Four priority research needs deemed desirable for improvement of present study results are described.

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Judson E. Brown acted as the primary field assistant for this study. Several work study students and departmental secretaries provided various forms of technical assistance from time to time. Appreciation is also due to John A. Mason for graphical construction.

To those members of CSU's Fire Science and Technology Program that I was associated with, I thank you for the chance to "BS" with one another which proved to be the most rewarding experience of my graduate training.

Finally, I am indebted to the Great Lakes Forest Research Centre, Canadian Forestry Service, for the opportunity and support to complete this study.

## AUTOBIOGRAPHY

Martin Edward Alexander was born in Vallejo, California on 14 September 1952, the only son and first child of Charles Russell Alexander and Connie Elizabeth (Carte) Alexander. He graduated from high school at Val D'or, Quebec in 1970 and obtained his B.S. degree in Forest Management Science at Colorado State University (CSU) in 1974. In the summer of 1971 he worked for Domtar Woodlands Ltd. in northern Quebec on a precommercial thinning crew. During the summers of 1972 and 1973, he worked for the USDA Forest Service as a crew member on the Bighorn National Forest Interregional Fire Suppression Crew stationed at Greybull, Wyoming. During his sophomore year, he worked part-time for CSU's Forest and Wood Sciences Department and the Colorado State Forest Service. In his junior and senior years at CSU, he worked part-time for the National Fire-Danger Rating research work unit, then located at the Rocky Mt. Forest and Range Experiment Station, Fort Collins, Colo. Following graduation in June 1974 and until his return to CSU graduate school in January 1975, he was employed as a supervisory forestry technician engaged in wilderness fuel inventory and prescribed burning on the Nezperce National Forest headquartered in Grangeville, Idaho. In May 1976, he joined the Canadian Forestry Service as a Fire Research Officer at the Great Lakes Forest Research Centre located at Sault Ste. Marie, Ontario, where he is responsible for wildfire ecology and effects research, and assisting land managers in evaluating the role of fire in wilderness and park environments. He married the former Heather Ann Flanagan in November 1975.

## DEDICATION

It is with heartfelt affection that I dedicate this thesis to the love of my life, my wife Heather. Her love and patience throughout my graduate studies were the key to my completion.

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# CHAPTER 1 - INTRODUCTION

The lodgepole pine (*Pinus contorta* Dougl. var. *latifolia*) cover type represents approximately one-fourth of the total commercial forest acreage in the eastern Front Range of Colorado. The magnitude of wildfire history associated with lodgepole pine forests in this area is well known (Alexander and Sandberg 1976; Clements 1910; Mason 1915). Characterization of forest fuels is essential to our understanding and managing of lodgepole pine ecosystems in the presence and absence of fire (Anderson 1974; Brown 1975).

The composition and structure of the forest fuel complex must be described before the interaction between potential fire behavior and the environment can be examined constructively. Forest fuels vary widely in their distribution, physical characteristics, and influence on resulting fire behavior. Delineation of these fuels is required for systematic analysis. Fuels within a coniferous forest stand complex can be sorted into three stratas based on their vertical distribution and general properties-- ground, surface, and aerial (Brown and Davis 1973). Ground fuels include all burnable material below the loose surface litter layer and are comprised primarily of duff and submerged punky wood. Surface fuels are comprised of mainly fallen needle litter, twigs and branches, downed logs in various stages of decay, herbaceous vegetation, shrubs, and regeneration. Aerial fuels consist of live and dead burnable material in the overstory canopy-- primarily needle foliage, and branchwood but includes snags and live stem boles as well.

Fuel description provides the basis for characterization. "Fuel description is as it sounds-- a description of the fuel properties that are important for assessing fire potential" (Brown 1972). These properties can be determined directly in the field by inventory, or through prediction which requires known quantitative relationships between fuel complex properties and vegetative characteristics. Estimation may require a combination of inventory and prediction.

## Problem Statement

Much research has been directed towards lodgepole pine slash fuel complexes. Mathematical relationships between sapling and tree characteristics and crown fuel component weights presently exist for estimating slash fuel loading and for describing the aerial fuel strata in lodgepole pine stands (e.g., Brown 1976a, 1978; Brown et al. 1977). Fuel bed depth of slash complexes has been related to predicted loading (Albini and Brown 1978). Assessment of crown fire potential also requires two important spatial parameters of the aerial strata-- length and height to live crowns (Van Wagner 1977).

In Colorado, little basic information exists on descriptions of the ground and surface fuel stratas in lodgepole pine stands. Available fuels description data (Clagg 1975; Moir 1972; Moir and Grier 1969) is generally incomplete because of different study objectives, missing information, and lack of standardization. Sampling procedures are presently available (Anderson 1978; Brown 1974c, Brown 1976b; Brown and Marsden 1976) but the expense and allocation of time by land managers for field measurement hinders data acquisition. If fuels description information is to be easily acquired and used it must be tied to

existing forest inventory and vegetation mapping efforts (Anderson 1974; Brown 1972; Kiil 1967b, 1968; Muraro 1971; Sando and Wick 1972; Smith 1968). This approach offers a viable method that is compatible with a land manager's current capabilities and limitations.

## Purpose and Objectives

This study was initiated to determine if significant correlations existed between stand and site conditions and selected fuel complex characteristics to permit the development of prediction models. The primary objectives were as follows:

1. Determine and describe numerically the best fitting relationships between stand structure/site characteristics and ground and surface fuel strata depths and loading by size class distribution.

2. Determine and describe numerically the best fitting relationships between stand characteristics and distance to live crown base and live crown length.

Associated study objectives included: (1) characterize the lodgepole pine fuel complex according to stylized stand habit and phytosociological classification criteria, (2) acquire natural residue inventory information as part of Colorado's efforts in the National Fuel Classification and Inventory System (USDA Forest Service 1974b), (3) present a regional adaptation of the Brown and Marsden (1976) methodology for estimating fuel weights of two common shrubs found in Colorado lodgepole pine stands, and (4) initiate an exploratory investigation of the influence of lodgepole pine dwarf mistletoe (*Arceuthobium americanum* Nutt. ex Engelm.) parasitism effects on the fuel complex.

The present study is a segment of the research being conducted under Problem Area 1, *inadequate technology for effective fuel management on commercial timberlands of the central Rocky Mountains and Southwest,* as outlined in the USDA Forest Service's Rocky Mountain Forest and Range Experiment Station Fuel Management Research Work Unit charter (Dieterich 1977). This thesis is a contribution to furthering our ability to understand and manage fuels in lodgepole pine forests at their southern extent in the Rocky Mountains.

## CHAPTER 2 - BACKGROUND INFORMATION AND PREVIOUS INVESTIGATIONS

A prerequisite to appreciating fuels description in lodgepole pine stands is a basic understanding of: (1) the species' fire ecology in relation to fuels and fire behavior and (2) the breadth of lodgepole pine fuel complex dynamics-- production, decomposition, and accumulation. This chapter is devoted to a review of these two subjects. In the latter case, general principles are described and specific examples for lodgepole pine are noted if available.

A summary of "published" lodgepole pine ground and surface fuel measurement and prediction studies in the United States and Canada is included for comparison with the present study. Current work known to this author is noted. In addition, a review of past crown fuel prediction studies is included for completeness.

### Fire Effects

An excellent review of this subject is already available (Brown 1975). However, a few salient points are worth mentioning.

Lodgepole pine is a shade intolerant species that in most cases readily establishes itself after fire because of its serotinous cone habit and related seeding advantage. Fire assists directly and indirectly in exposing mineral soil, releasing soil nutrients essential to plant growth, increasing light to the soil layer by eliminating shade cover, increasing daily range in soil temperatures, and opening serotinous cones by breaking the resin bond.

Fuel characteristics are largely a product of stand structure which in turn is frequently affected by the nature of the preceding

fire. A large margin of variation in stocking after fire is possible--from low densities to "doghair" conditions. This extreme latitude in initial establishment and subsequent growth of a new stand which ultimately influences its physical development and susceptibility to stagnation, suppression mortality, fuel accumulation, etc., is associated with several stand history and site factors. These include but are not limited to: behavior of the stand establishing fire (e.g., intensity, duration), resulting seedbed conditions, age and density of parent stand, available seed supply and viability, fire frequency, depth and moisture content of duff layer, post-burn climatic conditions favorable to germination and seedling establishment, site conditions (excessively dry or moist sites), and competiton from post-fire vegetation (R.R. Alexander 1974; Brown 1975; Horton 1953, 1955; Muraro 1971; Smithers 1961; Stahlein 1943; Tackle 1959). The relationships involved are complex, interrelated, and for the most part poorly understood in quantitative terms. High-intensity fires on mesic and hydric sites generally provide good seedbed conditions resulting in adequate stocking provided the seed has not been exposed to lethal heat; low-intensity fires on these sites have just the opposite effect. High-intensity fires on xeric sites generally result in poor stocking because soil moisture-holding capacity is impaired (Horton 1953). Duff moisture is critical-- low moisture contents permit mineral soil exposure whereas higher contents promote moderate heat flux to the soil resulting in optimum conditions for vigorous resprouting of resident vegetation.

## Fuel Complex Dynamics

Both live and dead material is produced by forest vegetation. Martin et al. (1976) have provided a conceptual synthesis of aboveground tree component production. Total tree bole, branch, and foliage weight increase with age and DBH. The quantity of foliage and twigs level off early in the life of the stand, whereas the quantity of larger components increase for longer periods of time.

Live and dead stems contribute yearly increments of downed dead material through litter fall, stem attrition, and branch shedding through pruning. The normal annual increment of dead fuel may be increased tremendously by animal activity, forest pests and pathogens, and meteorological factors that kill a sizeable portion of tree stems in a stand.

Decomposition is the process by which biological and physico-chemical agents break down organic matter (Dickinson and Pugh 1974). Inherent decay resistance and temperature and moisture regimes are the primary factors inhibiting or promoting the process and relative rates of decay (Aho 1974). Fuel accumulation or generation is the net result of production and decomposition. On the average, the decomposition rate is about one half that of production (Beaufait 1971). It is conceivable that decomposition might eventually equal or exceed production although accumulation may never level off due to fluctuations in production and decomposition rates (Martin et al. 1976).

Moir (1972) studied growth increments and mortality of standing stems, branches, and foliage, and net primary production for 2 years in three northcentral Colorado lodgepole pine stands (stands 4.3, 1.1, and LH2-- refer to Table 1). Organic production and turnover in the three

Table 1.-- *Selected stand and site characteristics from William H. Moir's lodgepole pine litter fall study in Colorado.*

| Stand No. | Stand Characteristics[1] | | | | | | Site Characteristics[2] | |
|---|---|---|---|---|---|---|---|---|
| | x̄ DBH (in.) | Height[3] (ft.) | Stand Age[4] | Basal Area (ft²/A) | Density (#/A) | Site Index @ 100 yrs. | Exposure | Elevation (ft.) |
| 1.1 | 2.8 | 30 | 68 | 170 | 3,600 | 59 | E | 8,200 |
| 1.3 | 5.2 | 41 | 99 | 193 | 1,200 | 50 | NNE | 8,200 |
| 2.2 | 1.2 | 15 | 67 | 140 | 14,200 | 59 | NE | 8,300 |
| 4.1 | 2.6 | 28 | 68 | 180 | 4,400 | 62 | WNW | 8,450 |
| 4.3 | 4.7 | 26 | 67 | 85 | 700 | 40 | WNW | 8,450 |
| LH2 | 5.3 | 51 | 73 | 252 | 1,500 | 90 | E | 9,100 |

[1]Applies to live stems only. From Moir and Grier (1969).
[2]From Moir (1969).
[3]Based on at least five dominant trees.
[4]Reference year is 1966. Stand age is based upon oldest tree in the stand.

Table 2.-- *Annual litter fall measured over four years in six lodgepole pine stands by William H. Moir (adapted from Moir 1972).*

| Year | Stand No. | | | | | | | | | | | | Mean | | Number of Samples |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1.1 | | 1.3 | | 2.2 | | 4.1 | | 4.3 | | LH2 | | | | |
| | loading, T/A[1] | | | | | | | | | | | | | | |
| 1967 | 2.052 | 1.539 | - | - | - | - | - | - | - | - | - | - | 2.052 | 1.539 | 17 |
| 1968 | 1.605 | 1.204 | 2.310 | 1.714 | 1.650 | 1.155 | 2.096 | 1.468 | 1.338 | 1.178 | 1.695 | 1.356 | 1.866 | 1.346 | 52 |
| 1969 | 2.230 | 1.673 | 3.925 | 2.394 | 1.829 | 1.280 | 2.498 | 1.749 | 2.319 | 2.041 | 3.078 | 2.462 | 2.647 | 1.933 | 52 |
| 1970 | 1.650 | 1.238 | 2.007 | 1.224 | 1.115 | 0.781 | 1.740 | 1.218 | 1.338 | 1.178 | 2.409 | 1.927 | 1.710 | 1.261 | 52 |
| Mean | 1.885 | 1.414 | 2.914 | 1.777 | 1.531 | 1.072 | 2.111 | 1.478 | 1.665 | 1.466 | 2.394 | 1.915 | 2.083 | 1.520 | -- |

[1]First loading value for an individual stand includes needles, male and female cones, bark, and twigs. Second loading value includes only needles, males cones, and bark (value is based on a percentage figure from Table 3).

Table 3.-- *Composition of the 1967-68 annual litter fall in six lodgepole pine stands as determined by William H. Moir (adapted from Moir 1972).*

| Stand No. | Litter Fuel Component | | | | | | | | | | | | Number of Samples |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Needles | | | Male cones | | | Bark | | | Female cones | | Twigs | | |
| | T/A | % | %[1] | T/A | % | % | T/A | % | % | T/A | % | T/A | % | |
| 1.1 | 1.071 | 68 | 91 | 0.015 | 1 | 1 | 0.089 | 6 | 8 | 0.223 | 15 | 0.178 | 10 | 7 |
| 1.3 | 1.517 | 54 | 89 | 0.045 | 2 | 3 | 0.134 | 5 | 8 | 0.937 | 34 | 0.178 | 6 | 8 |
| 2.2 | 1.071 | 66 | 95 | 0.017 | 1 | 2 | 0.045 | 3 | 4 | 0.223 | 12 | 0.312 | 18 | 7 |
| 4.1 | 1.338 | 64 | 92 | 0.020 | 1 | 1 | 0.089 | 5 | 6 | 0.357 | 18 | 0.268 | 13 | 7 |
| 4.3 | 1.115 | 83 | 93 | 0.045 | 3 | 4 | 0.045 | 2 | 3 | 0.134 | 9 | 0.045 | 2 | 15 |
| LH2 | 1.160 | 72 | 90 | 0.089 | 4 | 7 | 0.045 | 4 | 3 | 0.178 | 10 | 0.178 | 10 | 8 |
| Mean | 1.212 | 68 | 92 | 0.039 | 2 | 3 | 0.075 | 4 | 5 | 0.342 | 16 | 0.193 | 10 | |

[1]First percentage value for an individual component is based on the total of all components. Second percentage value is based on total of needles, male cones, and bark. Rounding errors may cause the percentages to total around 100.

stands were approximately steady. The only meaningful net annual accumulation found was for stem wood.

Moir (1972) also sampled annual litter fall in six lodgepole pine stands (Table 1) over a four year period (1967-70). Litter fall measured included fallen needles, male cone strobili, seed cones, bark flakes, and twigs. Over the four year period, stand averages varied from 1.531 to 2.914 tons per acre (T/A) (Table 2). Moir found considerable variation in litter fall from year to year and throughout the season. In all stands, 1969 was the maximum litter fall year. However, year-to-year differences were not consistent from stand to stand. For example, 1970 was the year of least litter production in stand 2.2 but not LH2. Branch shedding was somewhat uniform throughout the year whereas needle fall was more sporadic. In only one year was there a conspicuous "peak season" of needle fall in late August and September. On the average, needles comprised 68 percent of the annual litter fall whereas twigs and seed cones contributed 10 and 16 percent of the total, respectively (Table 3). If twigs and seed cones are excluded from the total litter fall, needles composed 92 percent of the total (Table 3).

Small downed woody material comes from three principal sources. These include the lodgepole pine stems themselves as well as shrubs and shade tolerant tree species in the understory.

Lodgepole pine is a reasonably good natural pruner, but in occasional stands dead branches persist. Low density in the early development of lodgepole pine stands allows growth of large limbs that do not prune well naturally, even after crown closure (Tackle 1959). Shrubs eventually contribute small amounts of dead material that have been shaded out by subsequent growth. Climax species (e.g., spruce-fir)

advancement may also contribute small quantities as well as enhancing vertical fuel continuity.

Natural thinning due to suppression mortality is the principal factor influencing the abundance of small downed poles. Suppression mortality depends on the initial stocking. In stands where competition is not severe, suppression mortality contributes little to downed woody fuels. The absence of poles on the ground indicates that the stand was relatively open in its early history (Trappe and Harris 1958).

Large downed sound material comes from two sources-- initially fron snag attrition of the antecedent fire-killed stems and later in the stand's life cycle as a result of natural mortality as dictated by species longevity. Observations by Mason (1915), Lyman (1945), and Tackle (1959) indicate that lodgepole pine stems killed by fire may remain standing for 15-30 or more years. In northcentral Colorado, Clagg (1975) found that the numbers of standing fire-killed snags generally declined to zero by age 45. Through assessments of 8 lodgepole pine stands on the 1961 Sleeping Child Burn in western Montana, Lyon (1977) found at the end of 15 years, two thirds of the stems had fallen. He concluded that in 40 years nearly all stems would have fallen while a few would stand indefinitely.

Standing dead stems decay slowly, especially if they are heavily charred. Once they have fallen and are in contact with the soil surface, decay accelerates.

Mason (1915) suggested that fire-killed stems took 60-120 years to decay. In this case, decay relates to a point in time where this downed material no longer contributes measurably to rate of spread and intensity (Brown 1975; Fahnestock 1976, 1977). McFee and Stone (1966)

determined that rotten wood could persist in the duff layer for up to 130 years. Large downed rotten material is principally the result of fire-killed stems. The amount depends on the size and density of the stand at the time of fire (Pickford et al. 1977).

Insects such as the mountain pine beetle (*Dendroctous ponderosae* Hopk.) contribute to downed fuels by killing trees (Brown 1975), especially in overmature stands (R.R. Alexander 1974). Several fungal diseases such as lodgepole pine dwarf mistletoes, commandra blister rust (*Cronartium comandrae* Pk.), western gall rust, (*Peridermium harknessii* Moore), and several root, butt and heart fungi (e.g., *Polyporus circinatus* Fr., *Coniophora puteana* (Schum ex. Fr.) Karst., *Armillaria mellea* (Fr.) Quel; *Fomes pini* (Fr.) Karst. result in weakened trees, tops, and branches which are susceptible to wind and/or snow breakage (Alexander and Hawksworth 1975; Brown 1975; Nordin 1954). Wind, snow, and ice storms may cause significant quantities of downed woody fuels to be produced (Trappe and Harris 1958). Dense stands are especially susceptible to snow and ice storms. Stems are likely to experience windthrow on shallow soil sites.

Animal activity may also influence downed woody fuel quantities. The most notorious species for this in Colorado lodgepole pine forests is the red squirrel (*Tamiasciurus hudsonicus* var. *fremonti*). The squirrel's branch shearing for food, its cone caches and resulting middens contribute to litter fall and downed woody fuel loadings (Clements 1910; Moir 1972).

In an extensive reconnaissance of lodgepole pine forests in northwestern Wyoming and southwestern Montana, Trimble and Tripp (1949) provide some observations on the development of the forest floor after

fire. They note that in the early development of a fire origin stand "...much of the forest floor is exposed to the direct rays of the sun. A large part of the scanty needle fall from the young trees is quickly oxidized or is washed away by the direct force of rainfall on the unprotected earth. Thus the formation of a new humus layer is a slow process. It appears that, even when a burn is fully restocked, 30 to 40 years must elapse after establishment of the stand before any appreciable litter and humus layer begins to form. At 50 years the organic layer is still patchy but accelerated erosion has greatly decreased. Litter depth averages about one-half inch. The partially decomposed F horizon averages about the same. An incipient H...horizon is beginning to form...At 75 years the litter averages about the same depth as at 50 years but the F and H...horizons combined run from 1 to 1½ inches thick. Generally the F horizon is the thicker. Stands 100 years old have a...1- to 2-inch...layer of F and H combined...Where old stands (over 200 years) have not deteriorated sufficiently to open the crown canopy, humus from 3 to 6 inches deep is sometimes found..."

The depth of dead fuel is influenced by the amount and arrangement of downed material. Dead fuel depth likely goes through a series of peaks and lows because of settling and various disturbances. Biomass of understory vegetation decreases rapidly at the time of stand closure (Martin et al. 1976). Crown fuels change as the stand grows and develops. Stand density and stand growth determine fuel characteristics. As stand height increases, the average distance to live and dead crown bases, and clear bole length increases (Martin et al. 1976).

As noted earlier, temperature and moisture are the most important factors influencing fuel decomposition. Several physical and environmental

site characteristics including soil type, slope aspect and percent, elevation, and degree of shading in turn modify microclimatic conditions. Soil type influences surrounding humidity and moisture content of fuels, especially when the fuels are in contact with the soil surface. Decomposition generally increases with decreasing elevation. Accumulation on the other hand tends to increase with increasing elevation. Slope aspect must also be considered. Northerly exposures are typically cooler and wetter than southerly aspects. This effect may be modified by degree of slope. Steep slopes receive less direct solar insolation; thus the soil and residue surfaces are cooler and moister. However, steep slopes may be drier due to rapid runoff of surface precipitation and subsurface water. Shading generally maintaines moist conditions while decreasing temperatures.

Clagg (1975) ordinated duff depth against slope aspect. He concluded that duff depths were definitely lower on southerly aspects.

Pickford et al. (1977) speculated that fuel decay was faster on southerly aspects. Fahnestock (1976, 1977) observed faster deterioration of fire-killed stems at lower elevations because shorter, cooler summers at higher elevations inhibited wood decay.

Fire itself acts as a fuel decomposer. However, fuel quantities are both created and destroyed by low- and high-intensity wildfires.

## Fuel Measurement and Prediction

The loading and depth of forest floor, downed woody surface fuels, and understory vegetation in lodgepole pine stands have been measured either singly or collectively for a variety of purposes: evaluating fire potential in wilderness and park fire management planning,

animal forage potential, hydrologic considerations, fuel complex investigations, biomass production and distribution, plant and fuel development following fire, and fire behavior studies. A summary of pertinent stand and site information from completed work in the United States and Canada is contained in Table 4. These studies are referred to in the following sections on forest floor, woody surface fuels and understory vegetation.

A brief explanation on the philosophy behind fuel prediction studies and investigations of fuel development since time of last fire (the later approach is termed "fuel succession" from here on) follows. Fuel succession studies are based on the assumption that the various age classes sampled are the simultaneous representation of the same stand at different ages. Researchers attempt to reconstruct developmental sequences from data which may have been obtained from a wide range of sites. Dyrness (1973) has pointed out that only broad successional stages may be discerned by this approach. As previously pointed out, fuels are not only influenced by age of disturbance but also by differences in such uncontrolled variables as soil, elevation, and severity of disturbance. The only feasible method will probably be the examination of a spatial array of stands to simulate one stand aging. Fuel prediction studies consider more than just stand age.

Anderson (1975) has stressed the need for attempting to correlate plant community types with fuels as a basis for description. These community types could take the form of fuel, cover, forest, habitat, or vegetation types.

Table 4.-- *Number of stands and/or plots, and selected stand and site characteristics associated with published studies on lodgepole pine ground and surface fuels in the United States and Canada.*

| Reference | Location | Number of | | Stand Characteristics | | | Site Characteristics | |
|---|---|---|---|---|---|---|---|---|
| | | Stands | Plots | Stand Age (yrs.) | Stem Density (No./Acre) | Basal Area ($ft^2$/Acre) | Elevation (feet) | Aspect |
| M.E. Alexander (1974) | northern Idaho | - | 190 | - | - | - | 6,038 | 218° |
| Almeida (1969) | northwestern Wyoming | 47 | - | - | - (435-1,157) | - | - | - |
| Brown (1972) | northern Idaho | - | 41 | - | - | - | 6,660 | 24° |
| Brown (1974a) | northwestern Wyoming | 2 | - | 175(167-182) | - | - | - | - |
| Brown (1975) | northern Rocky Mtns.[1] | 9 | - | - | - | - | - | - |
| Clagg (1975) | northcentral Colorado | 17 | 94 | 107(1-370) | 796(0-3,280) | 100(0-212) | 9,637(8,700-10,300) | 185°(39-330°) |
| Hawkes (1978) and [2] | western Alberta | - | 160 | - (57-119) | 2,389(1,220-5,075) | - | - | - |
| Fahnestock (1976,1977) | northcentral Washington | 10 | 175 | 71(2-200) | 936(0-2,024) | 78(0-143) | 5,280(4,500-5,800) | - (0-360°) |
| Kiil (1967b) | southwestern Alberta | 15 | - | 70 | 599(230-1,240) | 108(52-163) | 4,300 | southerly |
| Lawson (1972) | northcentral British Columbia | 3 | - | 84(74-100) | 383(322-454) | 95(80-102) | 2,350 | - |
| Moir (1972) | northcentral Colorado | 6 | - | 74(67-99) | 4,267(700-14,200) | 170(85-252) | 8,450(8,200-9,100) | - (NNE-WNW) |
| Moir & Grier (1969) | northcentral Colorado | 8 | - | 72(67-99) | 4,538(700-14,200) | 169(85-252) | - | - |
| Muraro (1971) | southwestern British Columbia[3] | 25 | - | 84(19-199) | 2,113(340-8,140) | 176(70-240) | - (3,500-5,000) | - |
| Muraro (1971) | southwestern British Columbia[4] | 10 | - | 77(19-161) | 3,578(540-18,000) | 143(14-208) | - (3,500-5,000) | |
| Oberheu & Mutch (1975) | northwestern Wyoming | - | 147 | - | - | - | 7,175(7,000-8,400) | - |
| Peirce (1977) | Intermountain U.S. | - | 49 | - | - | - | - | - |
| Phillips (1973) | central Idaho | 1 | - | - | - | - | 6,600 | - |
| Pickford et al. (1977) | northwestern Washington | 1 | - | 100 | 1,188 | 210 | 4,700 | east |
| Reynolds (1971) | southeastern Wyoming | 40 | - | 121(71-265) | - | 198(74-345) | 9,444(8,725-10,500) | - (0-360°) |
| Tisdale (1950) | central British Columbia | - | - | - | - | - | - | - |
| Trappe & Harris (1958) | northeastern Oregon | 50 | - | - | - | - | - | - |
| Wallmo et al. (1972) | central Colorado | 10 | - | - | - | - | - | - (NW-NE) |

[1]Includes northern Idaho, Montana, and Wyoming.
[2]Personal communication with Brad C. Hawkes, Graduate Student, Dep. For. Sci., Univ. Alta., Edmonton. October 24, 1978.
[3]Refers to Table 5.
[4]Refers to Table 7.

Forest Floor

The duff layer as described here refers to the fermination and humus layers. Litter as defined here is composed of fallen needles, bark flakes, cone scales, and male cone strobili. Differences in delineating forest floor horizons and litter composition hinder a complete comparison for all studies. Another complicating factor is the disregard for inorganic substances. Moir and Grier (1969) found that litter and duff samples taken from the field (basis: 8 stands) were composed on the average of 10 (range: 7-16) and 55 (range: 48-62) percent inorganic substances. Muraro (1971) found that mineral soil content of forest floor samples ranged up to 60 percent of dry sample weight. Fuel and fire research scientists have removed the inorganic residue using a muffle furnace. Other disciplines have not universally accounted for inorganic substances when reporting forest floor weights (e.g., Reynolds 1971).

Reported duff depths, litter, duff and total forest floor loadings in the United States and Canada are summarized in Table 5. Duff can vary from zero depth to 3.6 inches. Brown (1975) noted that he had never seen duff average more than 5 centimeters (1.97 inches) for many stands sampled in the Intermountain Region of the United States and that stands frequently average approximately 2 to 3 centimeters (0.79 to 1.18 inches). Stands with average depths exceeding 2 inches probably exhibit a large amount of rotten material (Fahnestock 1976, 1977; Pickford et al. 1977).

Litter loadings are reported to vary from 0.1 to 2.2 T/A. Duff loading is dependent on duff depth and bulk density. Reported values

Table 5.-- *Summary of published studies on duff depth, litter loading, duff loading, and total forest floor loading in lodgepole pine stands of the United States and Canada. Values in parenthesis refer to range reported.*

| Reference | Duff Depth, in. | Forest Floor Loading, T/A | | |
|---|---|---|---|---|
| | | Litter | Duff | Total |
| M.E. Alexander (1974) | 0.6 | 0.3 | 12.8 | 13.1 |
| Brown (1972) | 0.3 | 0.3 | 5.1 | 5.4 |
| Brown (1974a) | 0.9 | - | - | - |
| Brown (1975) | - | - | - | - (5.3-29.0) |
| Clagg (1975) | 1.0(0.0-2.7) | - | 15.8(0.0-42.6) | - |
| Fahnestock (1976,1977) | - | - | - | 23.5(5.8-49.9) |
| Hawkes (1978) | 1.8(0.6-3.6)[1] | - | 22.7(7.6-50.2)[1] | - |
| Kiil (1967b) | - | 1.2(0.1-2.8) | 20.8(12.6-30.4) | 22.0(14.3-30.6) |
| Lawson (1972) | - | - | - | 6.9(5.0-8.4) |
| Moir (1972) | - | 1.5(1.1-1.9) | - | - |
| Moir & Grier (1969) | - | 1.8(1.7-2.2) | 10.0(6.6-12.8) | 11.8(8.3-14.6) |
| Muraro (1971) | - | - | - | 11.7(3.9-41.9) |
| Oberheu & Mutch (1975) | 1.3 | 0.7 | 28.9 | 29.6 |
| Peirce (1977) | 0.8(0.0-2.3) | - | - | - |
| Pickford et al. (1977) | 0.8 | - | 12.0 | - |
| Reynolds (1971) | 1.1(0.6-2.1) | - | - | - |

[1]Personal communication with Brad C. Hawkes, Graduate Student, Dep. For. Sci., Univ. Alta., Edmonton. October 24, 1978.

range from zero to a high of 50.2 T/A. Total loading of combined litter and duff layers might well exceed 50 T/A.

Clagg (1975) plotted duff depth versus stand age and noted a steady increase up to approximately 110 years and then a gradual decline. Duff depth was plotted as a function of basal area but no statistics were reported. He concluded that duff depth was a function of time since fire, percent crown cover, and stand basal area.

Kiil (1967b, 1968) developed a regression equation for estimating litter weight from basal area ($R^2$ 0.45). Moir (1972) observed that stands with the least canopy mass have the lowest litter fall, and those with the greatest canopy mass have the highest litter fall.

Reynolds (1971) found basal area to be the single most highly correlated variable with total forest floor loading (r of 0.388). Fahnestock (1976, 1977) plotted total loading as a function of stand age concluding that weight increased with age. Moir and Grier (1969) found that stand density showed little relationship to forest floor quantities. Muraro (1971) found that no single stand or site variable satisfactorily explained the variation in total loading or depth although stand height and density provided the most useful relation. Brown (1966) notes that "Predictions of forest floor weight from stand characteristics are most dependable in stands having uniform structure, a history of no fire, and an origin on other than old forest floor material."

Woody Surface Fuels

The lack of standardization of size class diameters until recently (even this is sporadic) does not allow for complete comparisons of all size classes between studies. There have been two general trends in stratification-- to measure fuels less than and greater than three or

four inches in diameter. For this reason two separated summaries of downed woody surface fuels are presented in Tables 6 and 7. In addition, dead fuel depths associated with each study (when available) are included as well. Fuels have also been sampled in Glacier National Park in northwestern Montana (Jeske and Bevins 1976; Kessell et al. 1978), but because there was no separation of fuel types as to individual species in the literature, values could not be reported here.

The loading of fuels less than three inches in diameter is reported to vary from 0.26 to at least 9.66 T/A. Fuels less than four inches in diameter on the other hand vary from 1.20 to at least nine and one half T/A. Quantities of large downed material greater than three and four inches in diameter have been found to range from 0.3 to 63.3 and 1.1 to 99.2 T/A, respectively. Dead fuel depths have averaged from to 0.5 to 16.8 inches.

Peirce (1977) conducted a $t$ test analysis to test for equality of mean fuel descriptors between USDA Forest Service Region 4 (Utah, western Wyoming, central Idaho) lodgepole pine data and the present study (Region 2) data. The null hypothesis was rejected suggesting that significant differences between areas does exist.

Clagg (1975) and Fahnestock (1976, 1977) have each conducted fuel succession studies. Clagg (1975) stated that large sound material dominated throughout the stand life cycle except for the period from 50 to 150 years. Rotten material showed an approximate inverse relationship with sound debris. Due to the variability of the data for the smaller size classes, no definite conclusions could be drawn. Fahnestock (1976, 1977) came to the same conclusion. For the larger fuels, Fahnestock noted maxima at approximately 25, 55 and 400 years.

Table 6.-- *Summary of published studies on downed woody surface fuels < 3.0 inches in diameter and > 3.0 inches in diameter, and dead fuel depth in lodgepole pine stands of the United States and Canada. Values in parenthesis refer to the range reported.*

| Reference | Loading by Downed Woody Size and Composite Class, T/A | | | | | | | Dead Fuel |
|---|---|---|---|---|---|---|---|---|
| | <0.25" | 0.25-0.99" | 1.0-2.99" | <3.0" | 3.0"+R | 3.0"+S | 3.0"+R & S | Depth, In. |
| Brown (1974a) | - | - | - | 4.86 (4.34-5.38) | - | - | 21.8 (16.5-27.0) | 12.3 (10.8-13.7) |
| Clagg (1975) | - | 0.98 (0.0-3.72) | 2.39 (0.0 -9.66) | - | 6.2 (0.0-23.9) | 11.3 (0.0-32.5) | 16.9 (0.6-32.5) | - |
| Hawkes (1978) | 0.16[1] (0.07-0.26) | 1.01[1] (0.46-1.43) | 2.28[1] (0.78-3.44) | 3.44[1] (1.31-4.94) | 26.1[1] (1.4-55.4) | 2.5[1] (0.25-7.93) | 28.6[1] (3.8-63.3) | 4.2 (2.3-9.3) |
| Lawson (1972) | - | - | 0.33 | 0.52 (0.26-0.87) | - | - | 1.1 (0.4-1.9) | - (1.0-1.3) |
| Oberheu & Hutch (1975) | 0.13 | 0.52 | 0.99 | - | 2.8 | 4.2 | 9.0 | - |
| Peirce (1977) | 1.18 (0.0-5.39) | 5.81 (0.15-28.20) | 2.29 (0.30-7.40) | - | 11.1 (0.6-29.3) | 4.7 (0.0-25.3) | 15.8 | 2.8 (0.5-5.4) |
| Pickford et al. (1977) | - | - | - | 2.70 | - | - | 23.9 | - |

[1]Personal communication with Brad C. Hawkes, Graduate Student, Dep. For. Sci., Univ. Alta., Edmonton. October 24, 1978.

Table 7.-- *Summary of published studies on downed woody surface fuels < 4.0 inches in diameter and > 4.0 inches in diameter, and dead fuel depth in lodgepole pine stands of the United States and Canada. Values in parenthesis refer to the range reported.*

| Reference | Loading by Downed Woody Size and Composite Class, T/A | | | | | | | | Dead Fuel |
|---|---|---|---|---|---|---|---|---|---|
| | <0.20" | 0.20-0.60" | <0.60" | 0.60-4.00" | <4.0"+ | 4.0"+R | 4.0"+S | 4.0"+R & S | Depth, In. |
| M.E. Alexander(1974) | 0.13 | 0.16 | 0.29 | 1.43 | 1.72 | 6.9 | 6.0 | 12.9 | 3.7 |
| Brown (1972) | 0.10 | 0.43 | 0.53 | 3.14 | 3.67 | 18.2 | 13.3 | 31.5 | 3.7 |
| Brown (1974a) | 0.17 (0.14-0.20) | 0.89 (0.82-0.96) | 1.06 (0.96-1.16) | - | - | - | - | - | 12.3 (10.8-13.7) |
| Brown (1975) | - | - | - (0.22-1.16) | - (1.16-8.30) | - | - | - | - (3.5-31.5) | - |
| Fahnestock (1976,1977) | - | - | - | - | 3.33 (1.20-4.80) | - | - | 53.1 (5.2-99.2) | 7.1 (0.7-16.8) |
| Kill (1967b) | - | - | 0.25[1] (0.0-0.78) | - | - | - | - | - | - |
| Muraro (1971) | - | - | 0.37[1] (0.10-0.70) | 3.47[1] (1.10-8.50) | 3.84 (1.40-8.80) | - | - | 7.3 (1.1-17.3) | - |

[1]The diameter limit was actually 0.5 inches.

Muraro (1971) found in general that simple correlation coefficients between stand and fuel characteristics were less than 0.4. Exceptions mainly dealt with dead stem characteristics. In Muraro's opinion "...regressions...explaining 16% of the population variance, are of little use...as a means of predicting the fuel complex". Multiple regression analysis did not improve the use of stand characteristics as a means of predicting fuel characteristics. Inability to document conditions at the time of stand establishment and subsequent stand history were considered most responsible for the poor correlations. Muraro suggested that more accurate fuel preciction would likely be achieved by simulation techniques that include subroutines for initial fuel complexes, types of disturbance, and time related appreciation and depreciation of individual fuel components within the fuel complex.

Kiil (1967b, 1968) found correlations among surface fuels and stand characteristics were too weak for prediction purposes. He concluded that fuel variability was responsible for the poor relationships.

Understory Vegetation

Lodgepole pine forests characteristically lack large quantities of understory vegetation. Very dense stands have almost no ground vegetation whereas more open stands generally approach full ground cover (Tackle 1959). Vegetation weights generally decrease with increasing stand density (Kiil 1967b, 1968). Trappe and Harris (1958) observed that in the Blue Mountains of northeastern Oregon the better sites tended to have less ground cover than poor sites and that there were more forbs than grasses and shrubs on the best sites.

Total understory vegetation loading has been reported to vary from 0.002 to 8.450 T/A (Table 8). Trappe and Harris (1958) found that on the average shrubs made up approximately 65 percent of the total understory vegetation weight. M.E. Alexander (1974), Brown (1972), Oberheu and Mutch (1975), and Phillips (1973) report means of 70, 73, 6, and 78 percent respectively. Kiil (1967b) and Hawkes (1978) found that percent shrub weight varied from 0 to 92 ($\bar{x}$ 27) and 76-96 ($\bar{x}$ 88) percent, respectively. Depending on their density, shrubs influence the spread of surface fires by partially supporting fine fuels (primarily needle litter and small twigs) in a more optimumly aerated fuel bed than would form otherwise (Fahnestock 1976, 1977; Lawson 1972; Muraro 1964). Loading of shrubs and herbaceous plants have varied from zero to 8.1 and 0.130-0.537 T/A, respectively (Table 8).

Few studies have measured live fuel depth. Reported work to date indicates a range from 6.0 to 15.4 inches.

Muraro (1971) related understory vegetation weights to plant community types. Kiil (1967b, 1968) regressed basal area on understory vegetation with a resulting coefficient of determination of 0.49.

Brown and Marsden (1976) recently formulated regressions using various combinations of height and/or percent cover for estimating fuel weights of grasses, forbs, and small woody plants in Norhtern Rocky Mountain stands including kinnikinnick (*Arctostaphylos uva-ursi* L. Spreng.), a low shrub that commonly dominates low elevation lodgepole pine stands in Colorado. Brown (1976b) developed linear regression equations for determining the above ground biomass of several northern Rocky Mountain shrubs including *Vaccinium scoparium* Leiberg which with *V. myrtillus* L.

Table 8.-- *Summary of published studies on shrub vegetation loading, herbaceous vegetation loading, and total understory vegetation loading, and live fuel depth in lodgepole pine stands of the United States and Canada. Values in parenthesis refer to the range reported.*

| Reference | Understory Vegetation, T/A | | | Live Fuel Depth, in. |
|---|---|---|---|---|
| | Shrubs | Herbaceous[1] | Total | |
| M.E. Alexander (1974) | 1.237 | 0.537 | 1.774 | 15.4 |
| Almeida (1969) | - | - | 0.357(0.234-0.413) | - |
| Brown (1972) | 1.200 | 0.450 | 1.650 | 14.6 |
| Hawkes (1978) | 2.740(0.500-8.100) | 0.216(0.130-0.350) | 2.956(0.630-8.450) | - |
| Kill (1967b) | 0.574(0.0-4.100) | 0.630(0.330-0.980) | 1.210(0.470-4.440) | - |
| Lawson (1972) | - | - | 0.174(0.131-0.218) | 10.0(6.0-12.0) |
| Muraro (1971 | - | - | 0.947 | - |
| Oberheu & Mutch (1975) | 0.030 | 0.273 | 0.303 | - |
| Phillips (1973) | 0.112 | 0.390 | 0.502 | - |
| Tisdale (1950) | - | - | 0.208 | - |
| Trappe & Harris (1958) | - | - | 0.125(0.002-0.300)[2] | - |
| Wallmo et al. (1972) | - | - | 0.196 | - |

[1]Includes forbs, grass, grass-like plants, and herbs.
[2]Shrubs made up approximately 65% of the weight (Trappe and Harris 1958).

forms the whortleberry complex typical of high elevation lodgepole pine stands in Colorado.

Current Work

Mathews (1975) has been investigating the relationships between stand characteristics and fuel loadings and depths including the influence of mountain pine beetle, lodgepole pine dwarf mistletoe, and fire history in lodgepole pine stands of southwestern Montana. Photo series of natural residues in lodgepole pine stands as part of the National Fuel Classification and Inventory System (USDA Forest Service 1974b) are being developed for the Pacific Northwest[1] and Northern Rocky Mountain[2] areas. These series are designed to illustrate fuels of different levels as a result of natural influences through photos and a companion data sheet that summarizes pertinent stand and fuel characteristics.

Crown Fuels

In terms of various types of aerial fuels, the quantity of material in live tree crowns is by far the most significant. Several studies have shown that weights of selected and collective components of tree crowns can be estimated from simple field measurements of stem and crown variables such as diameter-at-breast height and total height, and crown length and width or any combination thereof. A synthesis of published crown fuel weight studies is shown in Table 9. Characteristically high correlations are noteworthy. Of all the studies listed, Brown's (1976a,

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[1]Personal written communication from Wayne G. Maxwell, Forester, USDA For. Serv., Pac. Northw. For. and Range Exp. Stn., For. Residues Prog., Portland, Oreg. November 22, 1978.

[2]Personal written communication from William C. Fischer, Research Forester, USDA For. Serv., Intermt. For. and Range Exp. Stn., North. For. Fire Lab., Missoula, Mont. November 17, 1978.

Table 9.-- *Summary of published lodgepole pine crown fuel prediction studies in the United States and Canada.*

| Reference | Study Area | Sample Trees | | Regression | | Weight Computation | | |
|---|---|---|---|---|---|---|---|---|
| | | Qty. | DBH(in.) | $X_i$(s)Selected[1] | $R^2$ | Graph | Table | Equation |
| Brown (1976a, 1978) | western Montana & northern Idaho | 45 | 1.2-16.1 | DBH,CL,H | 0.88 | | X[2] | X |
| Fahnestock (1960) | central Montana & northern Idaho | 51 | 2-17.9[2] | DBH,CL | (not given) | X | X | |
| Gary (1976) | southern Wyoming | 117 | 2.6-7.8 | DBH | .91 | X | | X |
| Johnstone (1970) | southeastern Alberta | 85 | 4.0-13.4 | DBH,H | .85/.89[4] | | | X |
| Johnstone (1971) | southeastern Alberta | 222 | 0.6-6.6 | DBH,H | .79 | | | X |
| Kiil (1967a) | southwestern Alberta | 101 | 0.9-21.1 | DBH,CW | .96 | X[5] | X | X |
| Kiil (1971) | southwestern Alberta | 63 | 1.5-9.1 | H,CW | .81 | | | X |
| Muraro (1971) | | 425 | 0.8-9.0[6] | DBH,HLC | .80[7] | X[8] | | X |
| | British Columbia | | | DBH,H | .49[9] | X[8] | | X |

[1]DBH = tree diameter at breast height; CL = crown length; H = total tree height; CW = crown width; HCL = height to live crown.
[2]Brown et al. (1977).
[3]From Brown (1978).
[4]For needle foliage and branchwood, respectively.
[5]Kiil (1965).
[6]Based on mean diameter at 18 different sampling plots.
[7]For live crown fuels only.
[8]Using DBH only and includes dead and live crown fuels. Muraro (1966) provides similar graph.
[9]For dead crown fuels only.

1978) is the most comprehensive and robust to date. The ability to predict crown fuel component weights from easily identifiable tree characteristics and a knowledge of D.B.H. size class distribution allows for estimation of slash fuel quantities, the result of silvicultural practices (i.e., clearcutting, precommercial thinning), and assessment of the aerial fuel complex in terms of crown fire potential. Prediction equations are most accurate when basic data is obtained from ground cruises although Kiil (1971) has shown that weights can be predicted quite accurately from low-level aerial photographs.

Muraro (1971) measured distance to live crown base and live crown length on 425 stems and related them to height and DBH, respectively. Resulting $R^2$ for both equations were 0.58. Trappe and Harris (1958) found that the ratio of live crown length to total tree height averages about 30 percent and may be as low as 20 percent.

# CHAPTER 3 - METHODS

## Study Area

The study area, in terms of sampling restriction, was defined as those lands containing the primary lodgepole pine forest element of the mid- to upper-montane and subalpine vegetation zones (approximately 8,300 to 10,000 feet in elevation) encompassing the Front Range portion east of the Continental Divide in northcentral Colorado ($39^{\circ}30'$-$41^{\circ}0'$ N latitude; $105^{\circ}30'$-$106^{\circ}40'$ W longitude). The general climate, geology, and soils of the area have been previously described by R.R. Alexander (1974) and Marr (1961).

## Field Procedures

### Stand Selection

One week's extensive preliminary field reconnaissance of the general study area, provided insight into the relative range and abundance of stand conditions and possible sample locations. USDA Forest Service cover type maps were consulted as well. This provided for an identification of conditions not commonly encountered; stands with average diameter at breast height (D.B.H.) exceeding 10 inches, and stand densities of less than 200 or greater than 8,000 stems per acre. From personal knowledge and consultation of available fire history literature (Alexander and Sandberg 1976) it was concluded that less than 70 and greater than 150 year age-classes were uncommon. Clagg (1975) had previously sampled seventeen lodgepole pine stands on predominately south slopes and at high elevations. Based on the above information, the

total effort during the field season phase of this study was to primarily sample stands that fell within the 70- to 150-age-class range found on northerly slopes at the lower- and mid-elevation ranges of lodgepole pine. The resulting data collection complemented rather than duplicated Clagg's (1975) efforts. Beyond this, accessibility of stand for sampling versus travel time and distance strongly influenced selection of sampled stands.

The specific stands sampled had to meet two criteria: (1) no direct evidence of man's interference (i.e., cutting) for the past 30 years and (2) be considered as a "stand", that is "a continuous tract of vegetation which is homogeneous as to composition and age" (Daubenmire 1976) as well as slope and aspect. Thirty years was selected as a minimum time period because it was felt by the study investigator, by that time, human influence on the site would have diminished to a large degree. The stands to be sampled essentially fell within Forest Cover Type 218 as defined by the Society of American Foresters (Anonymous 1967).

## Stand and Plot Layout

Each candidate stand was examined prior to actual plot establishment in an effort to avoid any obvious interruptions in stand continuity. Two types of plot layouts were used depending on the timber sampling method involved: (1) a diagonal line or two parallel lines (at least 50 feet apart) through the stand area with a minimum of fifteen plot points at $\frac{1}{2}$-chain intervals (33 feet) and (2) a $\frac{1}{10}$-acre plot area (37.2 foot radius) with five radiating lines equal distances apart.

In the first case, stand information was recorded at the first plot (from a random starting point) and every fifth plot point thereafter. Ground and surface fuels were measured on randomly selected transects (Brown 1974c) off the diagonal line at each plot point. In the second case, all stems falling within the area were measured accordingly. The ground and surface fuels were measured on the five radiating lines starting from the outside toward the plot center point. The direction of the lines was determined by selecting a random number between 1 and 360 (corresponding to a compass direction) and then placing each successive line at 72 degrees apart from the previous one. The plot center in the latter case was somewhat subjectively chosen. In all cases, fuels were sampled first and then stand characteristics.

## Data Collection

### Stand Information

Basic structure and mensuration characteristics were determined from one of three timber plot sampling techniques: (1) 10 basal area factor (BAF) variable plot (Avery 1967; USDA Forest Service 1974a) using a Spiegel Relaskop; (2) 1/300-acre fixed plot using a 6.8 foot pole as the radius measure (USDA Forest Service 1974a); or (3) $^1/_{10}$-acre fixed plot (delineated by a cloth tape radiated from the plot center) as used by Kiil (1967b, 1968). Within a one acre area, four sample points of the first two types and one of the last provided a minimum ten percent cruise of the stand. The 10 BAF variable plot was used in stands where the average D.B.H. exceeded 5.0 inches and the 1/300-acre fixed plot was used where D.B.H. was less than 5.0 inches. The $^1/_{10}$-acre fixed plot was used to sample stands where one portion of the same

general stand area was heavily infected with lodgepole pine dwarf mistletoe while the other portion was infected to a lesser degree but still of the same origin. Stands sampled were associated with a study of dwarf mistletoe effects on timber yield (Myers et al. 1971).

The following information was recorded for each individual "count" stem: (1) condition class (live stem, dead stem, or snag); (2) D.B.H. to the nearest tenth of an inch; (3) height to the nearest foot; (4) distance to live crown base to the nearest foot; (5) live crown length to the nearest foot (subtracting for dead top and gaps of greater than one foot); (6) tree species; and (7) 6-class dwarf mistletoe infection rating (Hawksworth 1977). Increment borings at D.B.H. and the heights of at least four dominants per sampled stand were taken for stand age and site index. A rough estimate of stand age was made in the field. A copy of the field tally form is included in Appendix A.

## Site Information

At each plot, aspect was measured to the nearest two degrees and terrain slope to the nearest percent. Elevation, physiographic site type, and slope configuration were recorded for the sample area as a whole.

Every effort was made to document the fire history of the sample area prior to the present stand establishment from available field evidence. The presence of charcoal, charred stumps and snags were noted. Where basal fire scars on veteran residuals were found, a cross-section was taken to determine past fire dates. These sections were then sent to the University of Arizona's Laboratory of Tree-Ring Research for preparation and dating.

Field notes were made regarding branching habit and vertical fuel continuity, presence of shrubs and regeneration, and factors thought to influence surface fuel conditions such as wind, ice, and snow damage, suppression and natural mortality, and animal activities. The percentages of dominant/codominant and intermediate/suppressed crown classes were ocularly estimated. Black and white print photographs and 35 mm color slides were taken of the sampled stand area and representative surface fuel conditions.

Each stand was "typed" according to the lodgepole pine series of Steen and Dix's (in prep.) vegetation classification for Colorado's subalpine forests. Each stand was keyed out to vegetation division, type, and phase (if applicable). The legal description (township, range, section, $\frac{1}{4}$ section, and $\frac{1}{4}/\frac{1}{4}$ section) and administrative unit (i.e., ranger district and national forest) of the stand area were noted for any future referencing purposes. A copy of the stand and site information form is included in Appendix A.

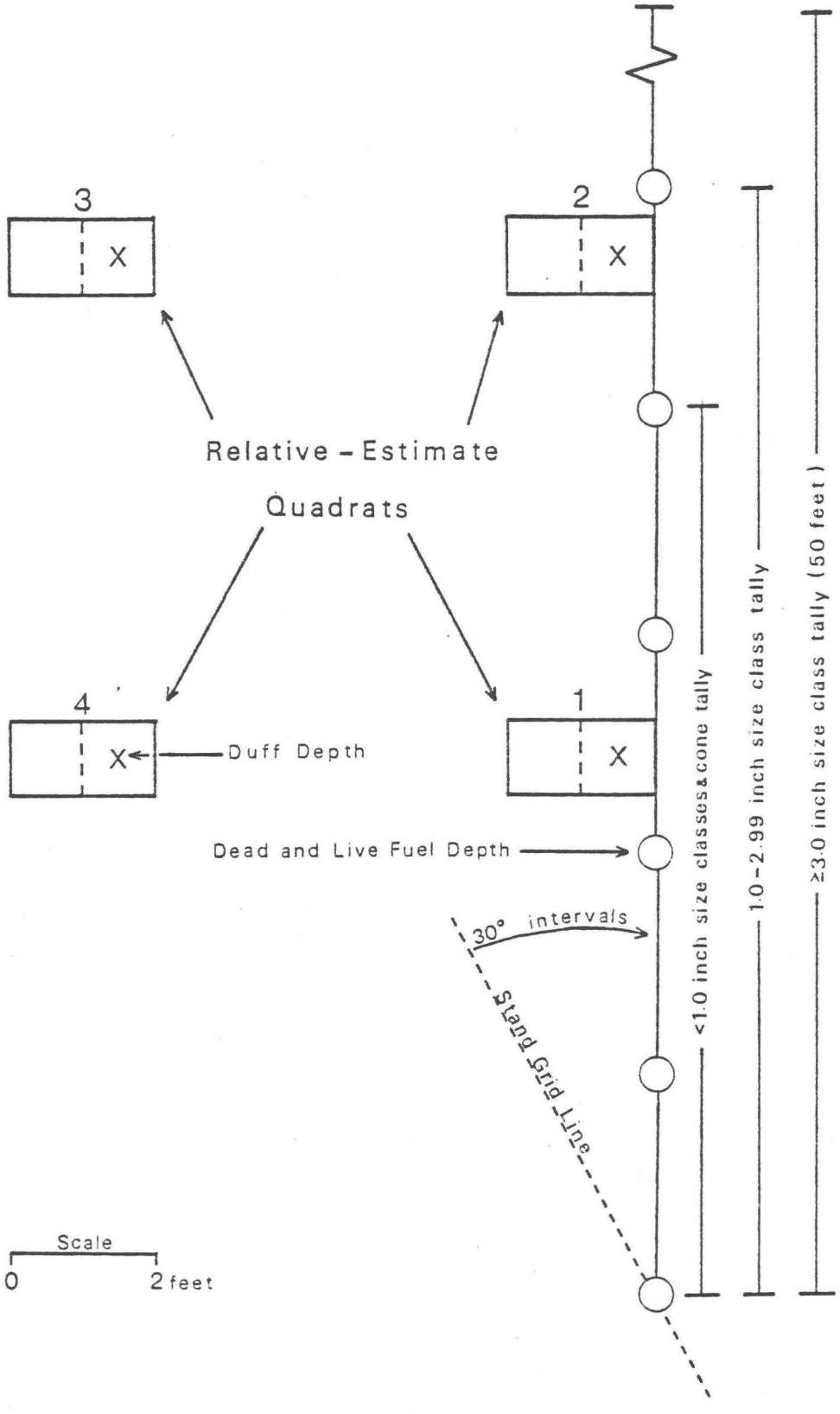
Ground and Surface Fuels

A diagramic representation of the fuel sampling plot is illustrated in Figure 1. A copy of field inventory form is included in Appendix A.

The depth of the duff layer (F and H layers combined) was determined from four systematic measurements per fuel transect and recorded to the nearest tenth of an inch (Fig. 1). This sampling intensity was designed to achieve sampling errors of twenty percent or less (Brown 1974c). Submerged punky wood was not differentiated from the rest of the duff layer because of similar bulk densities (McFee and Stone 1966).

Loading estimates were made of downed woody debris (including cones) less than 3.0-inches in diameter using the planar intersect technique

Figure 1.-- *Overhead layout of an individual fuel sampling plot.*



(Brown 1971, 1974c; Brown and Roussopoulos 1974). This method evolved from the line intersect technique first developed for fuel sampling by Van Wagner (1968). The three size classes of downed twigs and branchwood (<0.25, 0.25-0.99, and 1.0-2.99 inches) correspond to average moisture timelag classes (Fosberg 1970) and are the standard timelags used in the National Fire-Danger Rating System (Deeming et al. 1977). The <0.25 and 0.25-0.99 inch size classes, cones, and 1.0-2.99 size class intersections were tallied on 12- and 15-foot sampling plane lengths, respectively (Fig. 1). The degree of sampling intensity (number and length of sampling planes) was designed to furnish estimates having standard errors within 20 percent of the mean estimates based on past experience in northern Idaho and western Montana (Brown 1974c).

The line intersect technique (Van Wagner 1968) was used to sample rotten and sound material three inches and greater in diameter. Pieces were measured to the nearest inch at the point of intersection along 50-foot transect planes (Fig. 1). The 50-foot sampling plane length was selected as being the best estimate (Brown 1974c) to obtain reasonable percent errors.

The weight of the forest floor litter (primarily fallen needles but included female cone scales, male cone strobili, and bark flakes) or L layer of the forest floor was determined by the relative-estimate technique (Hutchings and Schmautz 1969) as developed and described by Brown (1974b) and expounded upon by Oberheu and Hartless (1975). This technique provides for a reasonable areal estimate of litter loading with minimum time involved. Four 1 x 2-foot metal frame quadrats were systematically placed in relation to the planar transect line (Fig. 1). The right-hand half (1.0 $ft^2$ area) of all four quadrats were viewed to

determine the one supporting the greatest quantity of material which became the "standard". The other three quadrats were assigned a code for percentage (1 = <5%; 2 = 6-20%; 3 = 21-40%; 4 = 41-60%; 5 = 61 - 80%; 6 = 81 - 95%; 7 = 96+%) as a portion of the standard. The material in the standard quadrat was collected by raking the loose material with the fingers then placing it in a paper bag. The bags were then stapled shut and labelled for laboratory evaluation. Litter collection quadrats that fell directly on squirrel caches and their resulting middens were not included in the final calculations. The sampling intensity was believed sufficient to obtain sampling errors of twenty percent or less.

Understory vegetation (shrubs and herbaceous plants) loading was determined by the relative-estimate technique using the same quadrats as the litter evaluations. No attempt was made to separate shrubs from herbaceous plants. The predominant understory vegetation found in lodgepole pine stands of the east Colorado Front Range are two low shrubs--kinnikinnick at low elevations and grouse whortleberry/myrtle at higher elevations. As in the case of litter weight determinations, a standard was selected and the other three quadrats assigned a percentage of the standard quantity (live and dead material). In addition, the standard was also given an actual cover estimate using the percentage classes. The height of vegetation within the standard quadrat was measured to the nearest inch "...as the distance from the forest floor to an apparent average top (plant height intergrated ocularly over the plot area)" as noted by Brown and Marsden (1976). An estimate of the total herbaceous vegetation volume that was dead was determined for each individual quadrat by assigning a percentage class code. All live and dead stem and leaf material above the forest floor within a vertical

projection of the quadrat frame (2.0 $ft^2$ area) was clipped and placed in a paper bag. The bags were then stapled and labelled for subsequent laboratory evaluation.

The slope of the planar/line intersect fuel transect was measured to the nearest percent. This was necessary in order to correct for the actual length of sample line and quadrat area on a slope (Brown 1974c).

Dead and live fuel bed depths were obtained from six measurements taken at three foot intervals along the planar transect line (Fig. 1). Depth was recorded to the nearest half-inch as the vertical distance perpendicular to the terrain slope from the bottom of the litter layer to the highest intersected (downed) material less than 3.0 inches in diameter up to a six-foot limit (Brown 1974c) within an imaginary projected 4-inch diameter cylinder (Albini 1975; Brown 1974a, 1974b; Oberheu and Hartless 1975). According to James K. Brown in Sneeuwjagt (1974), the 4-inch diameter is the theoretical spacing of particles having a surface-to-volume ratio of 1500 $ft.^{-1}$. The sampling intensity was designed to achieve percent errors of twenty percent or less.

## Office and Laboratory Procedures

### Stand Calculations

Stand structure and mensuration characteristics were determined from published equations and known relationships, based on basic overstory inventory data. Basal area, stand density, and average spacing between stems were determined from standard forest mensuration relationships (Avery 1967; Davis 1966). Gross stand volume in cubic feet per acre was determined from the equation given by Myers (1967). The crown competition factor, which compares growing space available to a tree with that represented by a vertical projection of the average crown

area of an open-grown tree of the same stem diameter, was calculated according to Alexander (1966). Determination of site index, which is a numerical measure of site productivity, was made by using the equations provided by Brickell (1970) based on Alexander's (1966) graphs. The average stand live/dead stem ratio, D.B.H., height, distance to live crown base, live crown length, species composition (based on stem density), and mistletoe infestation level were calculated by traditional means. All equations used are contained in Appendix B for completeness. Total stand age (or time since stand establishment) was determined by adding 9 years to the ring counts of increment cores taken at D.B.H. for site index determination (Alexander 1966) and/or results from the basal fire scar cross-section dating. Final ring counts were made in the laboratory using a binocular microscope.

Fuel Loadings and Depths

The physical properties required to calculate the loading of individual downed woody size classes using the planar and line intersect equations were obtained from the literature, personal contacts, and written correspondence (Table 10). Mean diameter of 3.0+ rotten and sound intersections was also determined. An average slope correction factor (Brown 1974c) based on the mean percent slope of all planar/line intersect transects encountered in the stand, was used to adjust for the actual length of line sampled. The planar intersect equation is documented in Appendix B.

Litter and understory vegetation samples collected in the field were oven-dried at 100°C for 24 hours and recorded to the nearest 100th of a gram. Moir and Grier (1969) have indicated that the percentage of

Table 10.-- *Physical properties of natural lodgepole pine fuels used in loading calculations.*

| Property Item | Specifics | Information Source |
|---|---|---|
| Squared quadratic-mean diameter ($d_q^2$) | $in^2$ | |
| <0.25" size class | 0.0201 | Brown (1974c); Brown and Roussopoulos (1974). |
| 0.25-0.99" size class | 0.344 | Brown (1974c); Brown and Roussopoulos (1974). |
| 1.0-2.99" size class | 2.87[1] | Brown (1974c); Brown and Roussopoulos (1974). |
| 3.0" + (sound and rotten) size class | --[2] | Brown (1974c). |
| cones | 1.39[3] | Brown[4]. |
| Specific gravity (s) | g/cc | |
| <0.25" size class | 0.48 | Brown (1974c). |
| 0.25-0.99" size class | 0.48 | Brown (1974c). |
| 1.0-2.99" size class | 0.41 | Brown[4]. |
| 3.0" + sound size class | 0.41 | U.S. Forest Products Laboratory (1955). |
| 3.0" + rotten size class | 0.30 | Brown (1974c). |
| cones | 0.66[5] | Lotan *in* Krugman and Jenkinson (1974). |
| Correction factor for vertical orientation bias ($\alpha$)[6] | [multiplier] | |
| <0.25" size class | 1.16 | Brown and Roussopoulos (1974). |
| 0.25-0.99" size class | 1.08 | Brown and Roussopoulos (1974). |
| 1.0-2.99" size class | 1.09 | Brown and Roussopoulos (1974). |
| 3.0" + (sound and rotten) size class | 1.00 | Anderson (1978); Brown (1974c). |
| cones | 1.00 | Brown[4]. |
| Bulk density ($\rho_b$) | $lb/ft^3$ | |
| duff (F+H layers) | 8.7 | Brown (1974a); Brown[4]. |

[1]Average value for species of Engelmann spruce, Douglas-fir, western red cedar, lodgepole pine, and mixed western larch/Douglas-fir/lodgepole pine; standard deviation was 1.34 percent (Brown and Roussopoulos 1974).

[2]The average diameter of all measured 3.0" + size class intersections is used.

[3]The specified value is actually a squared average diameter ($d_a^2$) value because a $d_q^2$ has not been developed as yet.

[4]Personal communication with James K. Brown, Principal Forest Fuels Scientist, USDA For. Serv., Intermt. For. and Range Exp. Stn., stationed at the North. For. Fire Lab., Missoula, Mont. Oct. 30, 1975.

[5]Mean value of range in source.

[6]Not a physical fuel property; used for solving the planar intersect equation (see Brown and Roussopoulos 1974).

inorganic residue in the litter layer is approximately ten percent on the average. For this reason, litter samples were not incinerated in a muffle furnace to adjust for this small amount of inorganic residue. Oven-dry weights of understory vegetation samples were divided by two to obtain values in pounds per square foot of sample area. Both litter and understory vegetation loadings were corrected for slope. Equations are documented in Appendix B.

Duff loading was estimated from a bulk density (organic matter in pounds per cubic foot) value for lodgepole pine (Table 10) provided by Brown (1974a) based on work in northwestern Wyoming. Bulk density values for lodgepole pine duff in Colorado have not been developed. The equation to estimate loading from depth using bulk density is documented in Appendix B.

Mean dead fuel depth was increased by one-half inch. This was a conservative adjustment for: (1) fuel bed disturbance due to laying out a steel tape to visualize the fuel transect plane and (2) fuel bed compression and displacement when attempting to reach the bottom of the litter layer with a wooden dowel used for depth measurement.

Clagg's (1975) lodgepole pine fuels description data and stand/site information were examined for compatability with the present study. Except for rotten material three inches and greater in diameter, the loadings of all downed woody fuel size classes were recalculated based on the physical properties found in Table 10 and intersection data contained in Clagg (1975) and data on file with the CSU Fire Science and Technology Program. Clagg (1975) did not tally the <0.25 inch size class fuels. Duff loading was also calculated as previously described for the present study.

Loading estimates of needle foliage, twigs, and branchwood contained within the crowns of sampled stands as basis for aerial fuel characterization were calculated according to procedures described by Brown et al. (1977). Dry weights were calculated by summarizing D.B.H. size class distribution by density or basal area depending on whether a fixed (density) or variable (basal area) plot was used in the overstory sampling. Final weights were adjusted for percent of intermediate and suppressed stems. The dry weights of stem boles of stands exhibiting an average D.B.H. of four inches or less were estimated from an equation provided by Brown (1976a). For stands where D.B.H. exceeded four inches, bole weight estimates were obtained from gross volume per acre and specific gravity (U.S. Forest Products Laboratory, 1955) of lodgepole pine wood. Crown bulk density was calculated according to Van Wagner (1978).

All fuel loadings were expressed in tons per acre (T/A). Fuel depths (live, dead, and duff) were expressed in inches (in).

## Data Analysis

### Descriptive Statistics

The sample mean ($\bar{x}$) and standard deviation(s) were calculated for all stand and site characteristics, and fuel descriptors by sampled stand. The range (maximum and minimum values) in the sample data was also determined. Sufficient information was presented to allow calculation of the standard error of the mean by sampled stand if so desired.

Percent error, defined as the standard error of the mean divided by the mean times one hundred percent, were calculated for all fuel description categories. The mean and range in percent error by number of plots per stand and an overall average was determined.

Sampled stands were portioned into two logical, stylized stand habit categories according to their mean live stem D.B.H.-- sapling (D.B.H. >5.0 inches) or pole/sawtimber (D.B.H. >5.0 inches). Sampled stands were also separated by vegetation division and type/phase according to Steen and Dix's (in prep.) vegetation classification system. The mean and range of individual ground and surface fuel descriptors were determined by stand habit and vegetation type. The $t$ statistic was used to test the null hypothesis that mean fuel descriptors of sapling and pole/sawtimber stands belong to the same population (Snedecor and Cochran 1967). Statistical significance was established at the ten percent ($P \leq 0.100$) level. Percentages by weight were determined as follows: (1) individual fuel loadings by strata (ground, surface, and aerial), and (2) individual fuel stratas versus the total fuel complex.

## Fuel Prediction

The development of numerical fuel prediction models followed a regression analysis approach (Draper and Smith 1966). Stand and site characteristics were selected as independent ($X_i$) variables and fuel descriptors as dependent ($Y_i$) variables (Table 11). Distance to live crown base was included as well. Log transformations were disregarded in favor of using fuel descriptions in their original units as dependent variables possessing numerical values were selected. Composite fuel loadings were also disregarded in lieu of treating each item as a separate entity. A matrix of simple correlation coefficients (r) between independent and dependent variables was constructed to determine if any individual linear relationship was apparent. Scatter diagrams were then plotted to depict curvilinear trends that were not readily

Table 11.-- *Dependent ($Y_i$, fuel descriptors) and independent ($X_i$, stand and site characteristics) variables selected for regression analysis.*

| Variable Designation | Variable Description | Units |
|---|---|---|
| Y(01) | <0.25" size class loading | T/A |
| Y(02) | 0.25-0.99" size class loading | T/A |
| Y(03) | 1.0-2.99" size class loading | T/A |
| Y(04) | 3.0" + rotten size class loading | T/A |
| Y(05) | 3.0" + sound size class loading | T/A |
| Y(06) | cone loading | T/A |
| Y(07) | litter loading | T/A |
| Y(08) | duff loading | T/A |
| Y(09) | dead fuel depth | in. |
| Y(10) | live fuel depth | in. |
| Y(11) | duff depth | in. |
| Y(12) | understory vegetation loading | T/A |
| Y(13) | distance to live crown base | ft. |
| X(01) | Live Stem Basal Area/Acre | $ft^2$/A |
| X(02) | Dead Stem Basal Area/Acre | $ft^2$/A |
| X(03) | Live Stem Density/Acre | #/A |
| X(04) | Dead Stem Density/Acre | #/A |
| X(05) | Live Stem Spacing | ft. |
| X(06) | Dead Stem Spacing | ft. |
| X(07) | Live Stem Volume/Acre | $ft^3$/A |
| X(08) | Dead Stem Volume/Acre | $ft^3$/A |
| X(09) | Live Stem Height | ft. |
| X(10) | Dead Stem Height | ft. |
| X(11) | Live Stem DBH | in. |
| X(12) | Dead Stem DBH | in. |
| X(13) | Crown Competition Factor | <125-500+ |
| X(14) | Site Index (@ 100-year base age) | 29-66 |
| X(15) | Stand Age | yrs. |
| X(16) | Elevation | ft. |
| X(17) | Terrain Slope | % |
| X(18) | Live Stem $DBH^2$·Height | $in^2$·ft. |
| X(19) | Live Stem DBH·Height | in.·ft. |
| X(20) | Dead Stem $DBH^2$·Height | $in^2$·ft. |
| X(21) | Dead Stem DBH·Height | in.·ft. |

discernable from the r values, and to visualize the degree of dispersion. An r matrix was also construced between independent variables. Intercorrelation between independent variables was checked for significant relationships. The r matrices and scatter diagrams provided the foundation for regression analysis, and eliminated those independent variables for which models could not be developed. Data stratification of the dependent variables by vegetation type, slope, aspect, etc., was disregarded because of the large sample size required for even a minimum number of situations.

The following regression analysis techniques in order of use were: least squares, polynominal, stepwise, and multiple linear. In most cases, the use of weighted regression techniques for the independent variables was deferred because of a lack of knowledge of the interaction with the dependent variable. The aim was to find the "best fit" without sacrificing simplicity. The final equations were judged on the basis of the coefficient of determination ($R^2$), $t$ test and sign of the regression coefficients, standard error of the estimate (SE) versus the mean ($\bar{Y}$) of the dependent variable, F statistic for significance of the regression, Y intercept, and the degree of intercorrelation between independent variables.

An evaluation test was then conducted to see how the regressions would perform under field conditions. Local data from literature was then sought in order to evaluate as many regressions as possible for comparison against predicted values.

Live Crown Length Prediction

Live crown length and foliage weight are required to calculate crown bulk density in order to assess crown fire potential (Van Wagner 1977). In order to develop a predictive model to characterize average stand live crown length, correlations among stand structure variables were first examined. Several combinations were then regressed on live crown length with the ultimate selection based on the same principles as the fuel prediction models. Local data from the literature was then sought for comparison with predicted values.

Shrub Weight Prediction

Understory vegetation plot characteristics (weight, percent cover, and height) from kinnikinnick and *Vaccinium* spp. dominated stands were utilized in the development of weight prediction equations using percent cover and/or height as independent variables. As a basis for selecting the most statistically significant equation, an r matrix was constructed between weight and the following independent variable sets: cover, cover squared, height, height squared, cover and height, cover and height squared, cover squared and height, cover times height, cover times height squared, and cover squared times height. Correlation between independent variables was checked for significant relationships. Final regressions were selected on the same basis as the fuel prediction models.

Dwarf Mistletoe Comparisons

The main interest concerning the effect of dwarf mistletoe parasitism on the fuel complex, pertained to the loading of downed woody material less then 3.0 inches in diameter, dead fuel depth, and distance to live crown base. The $t$ statistic was used to test the null hypothesis that mean fuel descriptors of the less infected stand area

and more heavily infected stand area belong to the same population (Snedecor and Cochran 1967). Statistical significance was established at the ten percent ($P \leq 0.100$) level.

# CHAPTER 4 - RESULTS

Twenty-eight stands were sampled during the summer and fall of 1975. This represents 365 planar intersect plots consisting of 17,800 feet of line, 365 litter and understory vegetation collections, 1460 duff measurements, and 2190 dead and live fuel depth measurements. Measurements on 3,718 live and dead stems were conducted and 167 increment cores were collected. Stands were sampled on three ranger districts within the Arapaho-Roosevelt National Forest, on the North Park Ranger District of the Routt National Forest and in Rocky Mountain National Park (Table 12). The legal description of these stands are noted in Table 12. In addition, timber sampling plot type and number, number of fuel transects, vegetation division and types/phases according to Steen and Dix (in prep.), and stand habit are noted by stand as well. Eight of a possible sixteen vegetation types (including type phases) were encountered during the sampling (Table 13). These represent the more common ones found in the eastern Colorado Front Range. Two stands could not be classified due to a lack of indicator plants in the understory.

## Stand and Site Characteristics

A range of stand and site conditions were obtained consistent with the stand selection process. Live stem D.B.H. and height varied from 1.9 to 10.6 ($\bar{x}$ 5.0) inches and 11.9 to 55.8 ($\bar{x}$ 31.1 feet, respectively (Table 14). For those sampled stands possessing dead stems, D.B.H. and height ranged from 0.9 to 10.4 inches and 8.3 to 45.0 feet, respectively (Table 14).

Table 12.-- *Type and number of timber plots, number of fuel transects, geographical location, and classification types by sampled stand.*

| Stand No. | Timber Plots Type[1] | Timber Plots No. | No. of Fuel Transects | Legal Description Twn. | Rge. | Sec. | 1/4 Sec. | 40. | Administrative Unit[2] | Vegetation | Stand Habit[4] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LP-01 | V | 5 | 20 | 7N | 73W | 9 | SW | SW | Poudre RD, Arapaho-Roosevelt NF | ARUV | P/ST |
| LP-02 | V | 4 | 15 | 7N | 73W | 15 | SE | NE | Poudre RD, Arapaho-Roosevelt NF | SHCA/JUCO/PINUS | P/ST |
| LP-03 | F1 | 4 | 15 | 7N | 73W | 15 | SE | NE | Poudre RD, Arapaho-Roosevelt NF | ARUV | S |
| LP-04 | F1 | 4 | 15 | 8N | 73W | 15 | SW | NW | Poudre RD, Arapaho-Roosevelt NF | ARUV | S |
| LP-05 | V | 4 | 15 | 8N | 74W | 24 | NE | SE | Poudre RD, Arapaho-Roosevelt NF | SHCA/VACC | P/ST |
| LP-06 | V | 4 | 15 | 9N | 74W | 12 | NW | NW | Redfeather RD, Arapaho-Roosevelt NF | CAGE/BERE | P/ST |
| LP-07 | V | 4 | 15 | 10N | 75W | 29 | NW | NE | Redfeather RD, Arapaho-Roosevelt NF | VACC/PYVI | P/ST |
| LP-08 | V | 4 | 15 | 10N | 76W | 19 | NE | NW | Redfeather RD, Arapaho-Roosevelt NF | VACC/ARCO/VACC | P/ST |
| LP-09 | F1 | 4 | 15 | 10N | 76W | 34 | SE | SE | Redfeather RD, Arapaho-Roosevelt NF | **** | S |
| LP-10 | V | 4 | 15 | 10N | 76W | 21 | NE | SE | Redfeather RD, Arapaho-Roosevelt NF | ARUV | P/ST |
| LP-11 | V | 4 | 15 | 8N | 73W | 8 | SE | SE | Poudre RD, Arapaho-Roosevelt NF | SHCA/JUCO/PINUS | P/ST |
| LP-12 | F1 | 4 | 15 | 5N | 74W | 24 | NE | SW | Rocky Mt. National Park | **** | S |
| LP-13 | V | 4 | 15 | 5N | 73W | 19 | NW | SW | Rocky Mt. National Park | ARUV | P/ST |
| LP-14 | F1 | 4 | 15 | 2S | 73W | 26 | NE | SW | Boulder RD, Arapaho-Roosevelt NF | ARUV | S |
| LP-15 | F1 | 4 | 15 | 5N | 77W | 22 | NE | SW | North Park RD, Routt NF | SHCA/PYVI/PINUS | S |
| LP-16 | V | 4 | 15 | 6N | 77W | 34 | SE | NE | North Park RD, Routt NF | SHCA/VACC | P/ST |
| LP-17 | V | 4 | 15 | 5N | 78W | 24 | SE | NE | North Park RD, Routt NF | SHCA/JUCO/PINUS | P/ST |
| LP-18 | F1 | 4 | 15 | 1S | 73W | 24 | NE | SW | Boulder RD, Arapaho-Roosevelt NF | SHCA/PYVI/PINUS | S |
| LP-19 | F1 | 4 | 15 | 7N | 72W | 16 | SE | SE | Poudre RD, Arapaho-Roosevelt NF | ARUV | S |
| LP-20 | V | 4 | 15 | 7N | 72W | 17 | NW | SW | Poudre RD, Arapaho-Roosevelt NF | SHCA/JUCO/PINUS | P/ST |
| LP-21 | V | 4 | 15 | 7N | 73W | 12 | SW | SE | Poudre RD, Arapaho-Roosevelt NF | SHCA/PYVI/PINUS | P/ST |
| LP-22 | F1 | 4 | 15 | 7N | 72W | 21 | NE | NE | Poudre RD, Arapaho-Roosevelt NF | SHCA/PYVI/PINUS | S |
| LP-23 | F2 | 1 | 5 | 10N | 75W | 27 | NE | NE | Redfeather RD, Arapaho-Roosevelt NF | VACC/PYVI | P/ST |
| LP-24 | F2 | 1 | 5 | 10N | 75W | 27 | NE | NE | Redfeather RD, Arapaho-Roosevelt NF | VACC/PYVI | |
| LP-25 | F2 | 1 | 5 | 10N | 76W | 33 | NE | NE | Redfeather RD, Arapaho-Roosevelt NF | ARUV | S |
| LP-26 | F2 | 1 | 5 | 10N | 76W | 33 | NE | NE | Redfeather RD, Arapaho-Roosevelt NF | ARUV | S |
| LP-27 | F2 | 1 | 5 | 9N | 73W | 7 | SE | NW | Redfeather RD, Arapaho-Roosevelt NF | ARUV | |
| LP-28 | F2 | 1 | 5 | 9N | 73W | 7 | SE | NW | Redfeather RD, Arapaho-Roosevelt NF | ARUV | S |

[1]V = 10 BAF variable plot; F1 = 1/300-acre fixed plot; F2 = 1/10-acre fixed plot.

[2]RD = Ranger District; NF = National Forest.

[3]Refer to Table 13 for description of code names.

[4]P/ST = Pole/Sawtimber stand; S = Sapling stand.

Table 13.-- *Vegetation divisions and types/phases encountered during the field sampling based on the lodgepole pine series of Steen and Dix's (in prep.) phytosociological classification of Colorado's subalpine forests. Common names are noted in brackets.*

| Code Name | Division | Type | Phase |
|---|---|---|---|
| ARUV | *Arctostaphylos uva-ursi* (L.) Spreng. [kinnikinnick] | - | - |
| CAGE/BERE | *Carex geyeri* Boott. [elk sedge] | *Berberis repens* Lindl. [creeping mahonia] | - |
| SHCA | *Shepherdia canadensis* (L.) Nutt. [buffalo-berry] | -- | |
| SHCA/VACC | *Shepherida canadensis* | *Vaccinium* spp.[1] | - |
| SHCA/PYVI/PINUS | *Shepherdia canadensis* | *Pyrola virens* Schweigg. [green-flowered pyrola] | *P. contorta*[2] |
| SHCA/JUCO/PINUS | *Shepherdia canadensis* | *Juniperus communis* L. [common juniper] | *P. contorta* |
| VACC | *Vaccinium* spp. | -- | -- |
| VACC/PYVI | *Vaccinium* spp. | *Pyrola virens* | - |
| VACC/ARCO/VACC | *Vaccinium* spp. | *Arnica cordifolia* Hook. [heartleaf arnica] | *Vaccinium* spp. |
| **** | (unable to key out due to lack of indicator plants) | | |

[1]Includes both *V. scoparium* Leiberg [grouse whortleberry] and *V. myrtillus* L. [myrtle whortleberry].

[2]Lodgepole pine.

Table 14.-- *Diameter-at-breast-height (D.B.H.) and height of live, dead, and combined live and dead stems by sampled stand.*

| Stand No. | Stem D.B.H. (in.) | | | | | | | | | Stem Height (ft.) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | live | | | dead | | | live & dead | | | live | | | dead | | | live & dead | | |
| | $\bar{x}$ | s | Range | $\bar{x}$ | s | Range | $\bar{x}$ | s | Range | $\bar{x}$ | s | Range | $\bar{x}$ | s | Range | $\bar{x}$ | s | Range |
| LP-01 | 5.7 | 1.4 | 2.9- 8.5 | 3.0 | 0.8 | 2.0- 4.1 | 5.4 | 1.5 | 2.0- 8.5 | 34.8 | 8.2 | 15-48 | 23.4 | 6.5 | 13-31 | 33.8 | 8.7 | 13-48 |
| LP-02 | 7.0 | 1.2 | 5.1- 9.6 | 0.0 | - | - | 7.0 | 1.2 | 5.1- 9.6 | 36.8 | 4.3 | 29-46 | 0.0 | - | - | 36.8 | 4.3 | 29-46 |
| LP-03 | 2.4 | 1.0 | 1.0- 5.1 | 1.5 | 0.3 | 1.0- 2.0 | 2.2 | 1.0 | 1.0- 5.1 | 16.4 | 4.0 | 15-27 | 20.7 | 6.1 | 9-37 | 20.7 | 6.1 | 9-37 |
| LP-04 | 2.9 | 1.2 | 1.0- 5.7 | 2.2 | 0.4 | 1.6- 2.7 | 2.8 | 1.2 | 1.0- 5.7 | 20.7 | 6.5 | 10-32 | 17.4 | 2.1 | 16-21 | 20.3 | 6.3 | 10-32 |
| LP-05 | 7.2 | 2.5 | 3.0-12.1 | 10.4 | 4.7 | 6.6-16.5 | 7.5 | 2.8 | 3.0-16.5 | 34.9 | 9.9 | 14-63 | 32.8 | 7.7 | 24-41 | 34.7 | 9.6 | 14-63 |
| LP-06 | 10.6 | 3.4 | 3.0-21.2 | 8.6 | 2.4 | 5.2-12.2 | 10.3 | 3.4 | 3.0-21.2 | 44.2 | 9.0 | 17-63 | 38.5 | 9.8 | 18-51 | 43.2 | 9.3 | 17-63 |
| LP-07 | 8.8 | 2.9 | 2.9-17.7 | 5.1 | 1.2 | 4.3- 6.5 | 8.7 | 2.9 | 2.9-17.7 | 51.6 | 6.7 | 24-63 | 33.0 | 6.9 | 25.37 | 50.9 | 7.5 | 24-63 |
| LP-08 | 8.0 | 2.0 | 2.4-12.1 | 9.3 | 2.9 | 7.2-11.3 | 8.0 | 2.0 | 2.4-12.1 | 48.5 | 8.8 | 19-65 | 45.0 | 15.6 | 34-56 | 48.3 | 8.9 | 19-65 |
| LP-09 | 3.2 | 1.2 | 1.6- 6.4 | 1.8 | 0.4 | 1.1- 2.7 | 2.7 | 1.2 | 1.1- 6.4 | 32.9 | 7.4 | 19-47 | 22.3 | 5.0 | 15-33 | 28.8 | 8.4 | 15-47 |
| LP-10 | 6.4 | 2.0 | 2.9-11.2 | 5.7 | 0.6 | 4.9- 6.3 | 6.4 | 2.0 | 2.9-11.2 | 41.7 | 5.7 | 25-61 | 35.5 | 2.4 | 34-39 | 41.4 | 5.8 | 25-61 |
| LP-11 | 8.7 | 1.6 | 5.4-11.6 | 0.0 | - | - | 8.7 | 1.6 | 5.4-11.6 | 44.8 | 4.9 | 35-56 | 0.0 | - | - | 44.8 | 4.9 | 35-56 |
| LP-12 | 2.6 | 1.0 | 1.1- 4.8 | 1.8 | 0.5 | 1.3- 3.0 | 2.5 | 1.0 | 1.1- 4.8 | 21.9 | 7.2 | 9-37 | 19.1 | 3.5 | 15-28 | 21.4 | 6.9 | 9-37 |
| LP-13 | 6.2 | 1.3 | 2.7- 8.7 | 3.5 | 0.8 | 2.5- 4.4 | 6.0 | 1.4 | 2.5- 8.7 | 33.4 | 5.5 | 13-47 | 25.5 | 3.9 | 19-29 | 32.8 | 5.8 | 13-47 |
| LP-14 | 2.8 | 1.2 | 1.0- 6.2 | 2.1 | 0.5 | 1.3- 2.8 | 2.6 | 1.1 | 1.0- 6.2 | 19.4 | 5.2 | 10-35 | 17.8 | 2.2 | 15-22 | 19.0 | 4.7 | 10-35 |
| LP-15 | 2.6 | 1.1 | 1.0- 5.8 | 1.8 | 0.8 | 1.0- 3.5 | 2.5 | 1.1 | 1.0- 5.8 | 25.2 | 7.4 | 13-43 | 19.0 | 4.3 | 15-26 | 24.1 | 7.3 | 13-43 |
| LP-16 | 8.8 | 2.5 | 2.0-13.8 | 0.0 | - | - | 8.8 | 2.5 | 2.0-13.8 | 55.8 | 11.9 | 17-73 | 0.0 | - | - | 55.8 | 11.9 | 17-73 |
| LP-17 | 5.5 | 1.6 | 1.9- 9.5 | 2.9 | 0.8 | 2.3- 3.5 | 5.4 | 1.6 | 1.9- 9.5 | 44.7 | 7.2 | 26-57 | 27.5 | 17.7 | 15-40 | 44.3 | 7.9 | 15-57 |
| LP-18 | 2.8 | 1.2 | 1.1- 6.0 | 1.7 | 0.5 | 1.0- 2.4 | 2.6 | 1.2 | 1.0- 6.0 | 21.7 | 6.4 | 9-35 | 16.3 | 1.7 | 15-19 | 20.9 | 6.2 | 9-35 |
| LP-19 | 3.7 | 1.5 | 1.2- 6.0 | 2.5 | 0.0 | 2.5- 2.5 | 3.6 | 1.5 | 1.2- 6.0 | 21.8 | 5.7 | 9-31 | 17.0 | 0.0 | 17-17 | 21.7 | 5.7 | 9-31 |
| LP-20 | 6.6 | 1.4 | 3.5- 9.6 | 5.5 | 1.3 | 3.6- 7.7 | 6.3 | 1.5 | 3.5- 9.6 | 37.9 | 6.0 | 19-47 | 33.9 | 5.2 | 28-43 | 36.8 | 6.1 | 19-47 |
| LP-21 | 6.0 | 1.4 | 2.6- 9.2 | 0.0 | - | - | 6.0 | 1.4 | 2.6- 9.2 | 37.1 | 5.9 | 21-49 | 0.0 | - | - | 37.1 | 5.9 | 21-49 |
| LP-22 | 2.3 | 0.9 | 1.1- 4.7 | 1.7 | 0.4 | 1.3- 2.0 | 2.3 | 0.8 | 1.1- 4.7 | 18.2 | 4.7 | 8-31 | 16.3 | 1.2 | 15-17 | 18.1 | 4.6 | 8-31 |
| LP-23 | 5.5 | 1.7 | 1.3- 9.0 | 0.0 | - | - | 5.5 | 1.7 | 1.3- 9.0 | 31.5 | 7.2 | 11-46 | 0.0 | - | - | 31.5 | 7.2 | 11-46 |
| LP-24 | 3.3 | 1.5 | 1.0- 6.9 | 1.9 | 0.0 | 1.9- 1.9 | 3.3 | 1.5 | 1.0- 6.9 | 22.5 | 7.5 | 7-37 | 16.0 | 0.0 | 16-16 | 22.5 | 7.5 | 7-37 |
| LP-25 | 2.5 | 0.9 | 0.6- 6.7 | 1.4 | 0.5 | 0.2- 3.8 | 2.1 | 1.0 | 0.2- 6.7 | 24.0 | 5.0 | 10-41 | 16.5 | 4.6 | 5-33 | 21.2 | 6.1 | 5-41 |
| LP-26 | 1.9 | 0.8 | 0.3- 5.7 | 1.2 | 0.5 | 0.5- 3.4 | 1.6 | 0.8 | 0.3- 5.7 | 14.8 | 4.9 | 5-36 | 10.7 | 2.9 | 4-21 | 13.2 | 4.7 | 4-36 |
| LP-27 | 3.5 | 1.5 | 0.5- 8.1 | 1.8 | 1.1 | 0.8- 7.3 | 3.2 | 1.6 | 0.5- 8.1 | 21.1 | 6.5 | 6-31 | 13.7 | 3.1 | 9-20 | 19.9 | 6.6 | 6-31 |
| LP-28 | 1.9 | 0.9 | 0.3- 5.8 | 0.9 | 0.4 | 0.2- 1.9 | 1.6 | 0.9 | 0.2- 5.8 | 11.9 | 4.1 | 5-27 | 8.3 | 2.1 | 5-14 | 10.8 | 4.0 | 5-27 |

The number of live stems per acre varied from 267 to 5400 ($\bar{x}$ 2067) (Table 15). Five of the sampled stands possessed no dead stems. The range of dead stems in the remainder of the stands was 10 to 2300 per acre (Table 15). Live stem basal area varied from 85.1 to 238.2 ($\bar{x}$ 152.4) square feet per acre (Table 16). Maximum basal area for dead stems was 32.5 square feet per acre (Table 16). Stand volume in for live stems ranged from 645.7 to 5368.2 ($\bar{x}$ 2436.0) cubic feet per acre (Table 17). Maximum dead stem volume sampled was 694.5 cubic feet per acre.

Between-tree spacing of live, dead, and combined live and dead stems is noted in Table 18. Average spacing between live stems ranged from 2.8 to 12.5 ($\bar{x}$ 4.6) feet. For those stands containing dead stems, the minimum and maximum spacing was 4.4 and 66.0 feet, respectively. Live and dead stem spacing varied from 2.6 to 12.8 ($\bar{x}$ 6.1) feet.

The mean distance to live crown base was 16.4 and values ranged from 6.3 to 30.8 feet (Table 18). Live crown length varied from 5.5 to 32.8 ($\bar{x}$ 14.5) feet (Table 18) for any one stand. On the average, live crown length represented 45 percent of the total tree height but this varied from 27 to 73 percent overall. For sapling stands the mean was 37 percent and 51 percent for pole/sawtimber stands.

Evidence of lodgepole pine dwarf mistletoe was found in four stands in addition to the 3 pair (6 stands) comparisons (Table 18). The mean infected level encountered according to the 6-class dwarf mistletoe rating system (Hawksworth 1977) varied from less than 0.05 to 5.6 (maximum value is 6.0) and the percent of infected trees per stand ranged from 2 to 100 percent.

Table 15.-- *Density of live and dead stems by sampled stand.*

| Stand No. | Density (No. of stems)/Acre | | | | | |
|---|---|---|---|---|---|---|
| | Live | | | Dead | | |
| | $\bar{x}$ | s | Range | $\bar{x}$ | s | Range |
| LP-01 | 853.9 | 150.0 | 685.9-1008.5 | 286.1 | 433.9 | 0.0- 979.0 |
| LP-02 | 392.7 | 34.7 | 348.2- 422.5 | 0.0 | - | - |
| LP-03 | 4050.0 | 387.3 | 3600.0-4500.0 | 675.0 | 450.0 | 300.0-1200.0 |
| LP-04 | 3000.0 | 1039.2 | 2100.0-4500.0 | 375.0 | 377.5 | 0.0- 900.0 |
| LP-05 | 339.7 | 99.9 | 218.8- 437.1 | 17.7 | 21.4 | 0.0- 43.3 |
| LP-06 | 277.1 | 80.8 | 206.4- 373.9 | 88.3 | 91.3 | 24.8- 221.3 |
| LP-07 | 504.4 | 238.1 | 243.3- 750.1 | 59.3 | 92.0 | 0.0- 193.8 |
| LP-08 | 375.2 | 101.8 | 265.3- 482.9 | 12.4 | 16.7 | 0.0- 35.4 |
| LP-09 | 2550.0 | 995.0 | 1200.0-3300.0 | 1575.0 | 928.7 | 300.0-2400.0 |
| LP-10 | 797.6 | 262.9 | 549.7-1111.1 | 57.8 | 68.7 | 0.0- 135.6 |
| LP-11 | 267.1 | 75.2 | 190.3- 357.7 | 0.0 | - | - |
| LP-12 | 5700.0 | 1606.2 | 4500.0-7500.0 | 975.0 | 895.8 | 0.0-2100.0 |
| LP-13 | 999.2 | 215.5 | 839.4-1305.9 | 239.3 | 352.2 | 0.0- 763.1 |
| LP-14 | 2550.0 | 995.0 | 1200.0-3600.0 | 675.0 | 1158.7 | 0.0-2400.0 |
| LP-15 | 4350.0 | 1558.8 | 3300.0-6600.0 | 900.0 | 489.9 | 300.0-1500.0 |
| LP-16 | 353.9 | 84.3 | 267.0- 442.3 | 0.0 | - | - |
| LP-17 | 1221.8 | 450.8 | 786.8-1694.6 | 109.0 | 218.0 | 0.0- 436.0 |
| LP-18 | 3900.0 | 1587.5 | 2400.0-6000.0 | 750.0 | 574.5 | 0.0-1200.0 |
| LP-19 | 2475.0 | 512.3 | 1800.0-3000.0 | 75.0 | 150.0 | 0.0- 300.0 |
| LP-20 | 420.6 | 183.1 | 231.1- 623.9 | 40.0 | 18.3 | 20.0- 60.0 |
| LP-21 | 616.2 | 225.0 | 395.3- 874.9 | 0.0 | - | - |
| LP-22 | 5400.0 | 1010.0 | 4800.0-6900.0 | 225.0 | 287.2 | 0.0- 600.0 |
| LP-23 | 730.0 | -- | -- | 0.0 | -- | -- |
| LP-24 | 1820.0 | -- | -- | 10.0 | -- | -- |
| LP-25 | 3790.0 | -- | -- | 2300.0 | -- | -- |
| LP-26 | 3600.0 | -- | -- | 2250.0 | -- | -- |
| LP-27 | 1980.0 | -- | -- | 380.0 | -- | -- |
| LP-28 | 4560.0 | -- | -- | 1940.0 | -- | -- |

Table 16.-- *Basal area of live and dead stems by sampled stand.*

| Stand No. | Basal Area ($ft^2$)/Acre | | | | | |
|---|---|---|---|---|---|---|
| | Live | | | Dead | | |
| | $\bar{x}$ | s | Range | $\bar{x}$ | s | Range |
| LP-01 | 148.0 | 40.9 | 100.0-200.0 | 14.0 | 21.9 | 0.0-50.0 |
| LP-02 | 102.5 | 22.2 | 70.0-120.0 | 0.0 | - | - |
| LP-03 | 146.5 | 45.0 | 105.5-210.4 | 8.3 | 5.5 | 2.8-14.8 |
| LP-04 | 164.8 | 48.3 | 115.7-226.9 | 10.2 | 7.7 | 0.0-18.6 |
| LP-05 | 92.5 | 12.6 | 80.0-110.0 | 10.0 | 11.5 | 0.0-20.0 |
| LP-06 | 165.0 | 20.8 | 140.0-190.0 | 32.5 | 22.2 | 10.0-60.0 |
| LP-07 | 207.5 | 69.9 | 140.0-300.0 | 7.5 | 9.6 | 0.0-20.0 |
| LP-08 | 127.5 | 38.6 | 90.0-180.0 | 5.0 | 5.8 | 0.0-10.0 |
| LP-09 | 162.6 | 14.4 | 150.3-180.3 | 30.0 | 15.2 | 11.9-48.5 |
| LP-10 | 172.5 | 17.1 | 150.0-190.0 | 10.0 | 11.5 | 0.0-20.0 |
| LP-11 | 110.0 | 24.5 | 90.0-140.0 | 0.0 | - | - |
| LP-12 | 238.2 | 69.8 | 149.9-302.8 | 18.7 | 20.8 | 0.0-46.6 |
| LP-13 | 205.0 | 19.1 | 190.0-230.0 | 15.0 | 17.3 | 0.0-40.0 |
| LP-14 | 124.8 | 29.9 | 96.2-164.8 | 17.5 | 27.2 | 0.0-57.2 |
| LP-15 | 192.4 | 59.5 | 137.6-264.6 | 19.5 | 13.1 | 8.1-38.1 |
| LP-16 | 147.5 | 25.0 | 110.0-160.0 | 0.0 | - | - |
| LP-17 | 200.0 | 53.5 | 150.0-260.0 | 5.0 | 10.0 | 0.0-20.0 |
| LP-18 | 192.8 | 27.2 | 159.7-224.9 | 13.3 | 12.5 | 0.0-30.1 |
| LP-19 | 213.3 | 75.8 | 136.5-314.5 | 2.6 | 5.1 | 0.0-10.2 |
| LP-20 | 100.0 | 33.7 | 60.0-140.0 | 40.0 | 18.3 | 20.0-60.0 |
| LP-21 | 117.5 | 22.2 | 100.0-150.0 | 0.0 | - | - |
| LP-22 | 176.3 | 53.6 | 114.4-245.2 | 3.7 | 4.5 | 0.0- 9.3 |
| LP-23 | 132.6 | -- | -- | 0.0 | -- | -- |
| LP-24 | 131.6 | -- | -- | 0.2 | -- | -- |
| LP-25 | 149.4 | -- | -- | 28.4 | -- | -- |
| LP-26 | 85.1 | -- | -- | 20.7 | -- | -- |
| LP-27 | 154.1 | -- | -- | 9.2 | -- | -- |
| LP-28 | 107.5 | -- | -- | 10.8 | -- | -- |

Table 17.-- *Volume of live and dead stems by sampled stand.*

| Stand No. | Volume ($ft^3$)/Acre | | | | | |
|---|---|---|---|---|---|---|
| | Live | | | Dead | | |
| | $\bar{x}$ | s | Range | $\bar{x}$ | s | Range |
| LP-01 | 2593.0 | 1034.2 | 1482.0-3717.0 | 170.8 | 286.9 | 0.0- 662.0 |
| LP-02 | 1904.5 | 508.9 | 1157.0-2297.0 | 0.0 | - | - |
| LP-03 | 1639.7 | 743.0 | 1051.2-2719.6 | 85.1 | 46.8 | 37.7- 129.9 |
| LP-04 | 1893.8 | 955.7 | 880.7-3130.7 | 99.7 | 77.1 | 0.0- 187.6 |
| LP-05 | 1633.2 | 196.2 | 1392.0-1872.0 | 172.2 | 205.3 | 0.0- 407.0 |
| LP-06 | 3659.5 | 387.2 | 3122.0-4037.0 | 642.0 | 454.7 | 152.0-1142.0 |
| LP-07 | 5368.2 | 1981.2 | 3572.0-8067.0 | 132.2 | 161.0 | 0.0- 327.0 |
| LP-08 | 3105.7 | 1087.0 | 1922.0-4557.0 | 121.0 | 146.7 | 0.0- 297.0 |
| LP-09 | 2835.9 | 508.1 | 2350.7-3286.8 | 359.1 | 183.5 | 184.0- 614.5 |
| LP-10 | 3614.5 | 419.5 | 3027.0-4007.0 | 186.0 | 214.9 | 0.0- 382.0 |
| LP-11 | 2479.5 | 452.5 | 2067.0-3062.0 | 0.0 | - | - |
| LP-12 | 2753.6 | 1232.9 | 1456.3-4332.4 | 195.2 | 221.7 | 0.0- 496.4 |
| LP-13 | 3437.0 | 424.0 | 3047.0-3947.0 | 204.0 | 243.5 | 0.0- 557.0 |
| LP-14 | 1319.0 | 462.1 | 834.8-1726.2 | 165.0 | 246.3 | 0.0- 521.2 |
| LP-15 | 2613.3 | 1198.0 | 1545.5-3997.4 | 225.9 | 186.9 | 79.4- 499.9 |
| LP-16 | 4129.5 | 793.1 | 3137.0-4982.0 | 0.0 | - | - |
| LP-17 | 4488.2 | 1108.4 | 3247.0-5632.0 | 73.0 | 146.0 | 0.0- 292.0 |
| LP-18 | 2207.1 | 630.2 | 1754.0-3131.2 | 122.6 | 110.8 | 0.0- 269.2 |
| LP-19 | 2426.2 | 882.8 | 1450.0-3633.7 | 26.0 | 51.9 | 0.0- 103.9 |
| LP-20 | 1912.0 | 690.6 | 1122.0-2807.0 | 694.5 | 332.6 | 312.0-1002.0 |
| LP-21 | 2198.2 | 468.9 | 1812.0-2857.0 | 0.0 | - | - |
| LP-22 | 1639.8 | 592.9 | 896.3-2341.4 | 38.4 | 45.9 | 0.0- 91.4 |
| LP-23 | 2106.5 | -- | -- | 0.0 | -- | -- |
| LP-24 | 1500.1 | -- | -- | 18.5 | -- | -- |
| LP-25 | 1808.2 | -- | -- | 251.7 | -- | -- |
| LP-26 | 645.7 | -- | -- | 127.6 | -- | -- |
| LP-27 | 1641.0 | -- | -- | 79.9 | -- | -- |
| LP-28 | 655.8 | -- | -- | 61.4 | -- | -- |

Table 18.-- *Spacing between live, dead and combined live and dead stems, distance to live crown base, live crown length, and dwarf mistletoe incidence by sampled stand.*

| Stand No. | Stem Spacing (ft.) Live $\bar{x}$ | Dead $\bar{x}$ | Live & Dead $\bar{x}$ | Distance to Live Crown Base (ft.) $\bar{x}$ | s | Range | Live Crown Length (ft.) $\bar{x}$ | s | Range | Dwarf Mistletoe Infestation $\bar{x}$ 6-Class Rating | % infested |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LP-01 | 7.1 | 12.3 | 6.2 | 19.5 | 5.7 | 7-33 | 15.4 | 6.9 | 3-31 | 0.0 | 0.0 |
| LP-02 | 10.5 | -[1] | 10.5 | 14.4 | 4.4 | 6-24 | 21.7 | 6.0 | 12-34 | 0.0 | 0.0 |
| LP-03 | 3.3 | 8.0 | 3.0 | 15.0 | 4.1 | 5-28 | 6.4 | 3.5 | 1-14 | 0.0 | 0.0 |
| LP-04 | 3.8 | 10.8 | 3.6 | 13.8 | 3.9 | 7-23 | 6.6 | 3.4 | 1-15 | 0.0 | 0.0 |
| LP-05 | 11.3 | 49.6 | 11.0 | 11.9 | 4.8 | 3-20 | 21.8 | 7.0 | 10-44 | 0.3 | 15.7 |
| LP-06 | 12.5 | 22.2 | 10.9 | 19.7 | 7.3 | 7-39 | 21.4 | 10.1 | 3-50 | 0.0 | 0.0 |
| LP-07 | 9.3 | 27.1 | 8.8 | 30.7 | 7.5 | 13-46 | 20.6 | 7.1 | 4-36 | 0.0 | 0.0 |
| LP-08 | 10.8 | 59.3 | 10.6 | 24.5 | 7.2 | 4-36 | 23.7 | 8.2 | 12-61 | 0.0 | 0.0 |
| LP-09 | 4.1 | 5.3 | 3.3 | 23.5 | 4.5 | 16-33 | 8.9 | 4.4 | 2-20 | 0.1 | 9.4 |
| LP-10 | 7.4 | 27.4 | 7.1 | 22.5 | 5.2 | 9-33 | 19.0 | 6.9 | 6-46 | 3.5 | 100.0 |
| LP-11 | 12.8 | -[1] | 12.8 | 11.7 | 6.6 | 2-28 | 32.8 | 7.5 | 14-47 | 0.0 | 0.0 |
| LP-12 | 2.8 | 6.7 | 2.6 | 14.7 | 5.4 | 6-25 | 7.0 | 3.3 | 1-16 | 0.0 | 0.0 |
| LP-13 | 6.6 | 13.5 | 5.9 | 14.2 | 5.9 | 3-26 | 19.1 | 6.3 | 4-33 | 0.0 | 0.0 |
| LP-14 | 4.1 | 8.0 | 3.7 | 12.4 | 3.6 | 5-19 | 6.6 | 3.5 | 2-17 | *[2] | 2.8 |
| LP-15 | 3.2 | 7.0 | 2.9 | 17.3 | 5.4 | 7-31 | 7.8 | 3.5 | 2-18 | 0.0 | 0.0 |
| LP-16 | 11.1 | -[1] | 11.1 | 30.8 | 9.5 | 1-51 | 24.9 | 9.7 | 5-46 | 0.0 | 0.0 |
| LP-17 | 6.0 | 20.0 | 5.7 | 26.8 | 5.2 | 7-35 | 17.6 | 7.5 | 5-47 | 0.0 | 0.0 |
| LP-18 | 3.3 | 7.6 | 3.1 | 14.0 | 4.3 | 3-22 | 7.0 | 3.7 | 1-18 | 0.0 | 0.0 |
| LP-19 | 4.2 | 24.1 | 4.1 | 8.4 | 3.4 | 3-15 | 13.4 | 5.3 | 3-21 | 0.0 | 0.0 |
| LP-20 | 10.2 | 13.4 | 8.1 | 23.6 | 7.1 | 4-37 | 14.0 | 5.5 | 2-27 | 0.0 | 0.0 |
| LP-21 | 8.4 | -[1] | 8.4 | 17.3 | 5.5 | 6-27 | 19.6 | 6.6 | 6-34 | 0.0 | 0.0 |
| LP-22 | 2.8 | 13.9 | 2.8 | 11.5 | 2.6 | 5-15 | 6.5 | 3.5 | 1-16 | 0.0 | 0.0 |
| LP-23 | 7.7 | -[1] | 7.7 | 11.0 | 3.4 | 4-18 | 20.2 | 7.3 | 2-32 | 0.1 | 5.5 |
| LP-24 | 4.9 | 66.0 | 4.9 | 10.0 | 4.0 | 2-19 | 12.5 | 5.8 | 2-33 | 1.9 | 89.6 |
| LP-25 | 3.4 | 4.4 | 2.7 | 15.8 | 3.5 | 6-27 | 8.2 | 4.2 | 1-23 | 4.0 | 98.2 |
| LP-26 | 3.5 | 4.4 | 2.7 | 8.2 | 3.1 | 2-19 | 6.6 | 4.5 | 1-30 | 4.8 | 99.2 |
| LP-27 | 4.7 | 10.7 | 4.3 | 10.6 | 4.2 | 3-25 | 10.4 | 5.3 | 1-25 | *[2] | 2.0 |
| LP-28 | 3.1 | 4.7 | 2.6 | 6.3 | 2.3 | 2-13 | 5.5 | 3.2 | 1-20 | 5.6 | 99.6 |

[1]A value of 208.7 was used in the correlation analyses; assumes a dead stem density of 1.0/A.

[2]Value is less than 0.05.

All twenty-eight stands sampled contained at least 93 percent lodgepole pine by composition (Table 19). Five stands contained small amounts of Engelmann spruce (*Picea engelmannii* Parry), Douglas-fir (*Pseudotsuga menziessii* var. *glauca* [Beissn.] Franco), and quaking aspen (*Populus tremuloides* Michx.).

The presence of charred snags, stumps and downed logs, charcoal on and below the forest floor, and basal fire scarred residuals confirmed that all sampled stands owed at least their present origin to fire. Mean stand age or time since stand establishment was 113 years and ranged from 57 to 282 years (Table 19). Fire history other than time since last fire (stand age) was documented by basal fire scar cross-sections and increment borings in nine stands (Table 19).

The number, age, and height of the tree dominants used to determine site index are documented in Table 20. The crown competition factor varied from 117.0 to 521.6 ($\bar{x}$ 258.0) (Table 20). Site index at a 100-year base age ranged from 29.4 to 66.0 and averaged 47.2.

Mean terrain slope was 22.3 percent and ranged from 6.8 to 50.0 percent (Table 21). Stands were sampled on all aspects but 75 percent were on northerly aspects. The distribution of stands by major aspect is as follows: north - 15; east - 6; south - 5; west - 2 (Table 21). Sixteen stands were 9,000 feet or less in elevation (Table 21). Elevations of sampled stands ranged from 8,300 to 9,950 feet in elevation with a mean of approximately 9,050 feet. The physiographic site type and slope configuration of each sampled stand is documented in Table 21.

From 135 black and white photos and 150 35 mm color slides, a representative collection consisting of 37 4 x 6 or 4 x 4 inch prints

Table 19.-- *Overstory tree species composition and documented fire history by sampled stand.*

| Stand No. | Tree Species Composition (%)[1] | | | | | | | | | | | | Stand Age[2] (yrs.) | Time Since Fire(s) Prior to Stand Establishment (yrs.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | lodgepole pine | | | Engelmann spruce | | | Douglas-fir | | | quaking aspen | | | | |
| | $\bar{x}$ | s | Range | $\bar{x}$ | s | Range | $\bar{x}$ | s | Range | $\bar{x}$ | s | Range | | |
| LP-01 | 100.0 | 0.0 | - | - | - | - | - | - | - | - | - | - | 89 | ?[3] |
| LP-02 | 100.0 | 0.0 | - | - | - | - | - | - | - | - | - | - | 103 | ? |
| LP-03 | 100.0 | 0.0 | - | - | - | - | - | - | - | - | - | - | 103 | ? |
| LP-04 | 100.0 | 0.0 | - | - | - | - | - | - | - | - | - | - | 82 | 32 |
| LP-05 | 100.0 | 0.0 | - | - | - | - | - | - | - | - | - | - | 82 | 28(9,61)[4] |
| LP-06 | 100.0 | 0.0 | - | - | - | - | - | - | - | - | - | - | 282 | ? |
| LP-07 | 100.0 | 0.0 | - | - | - | - | - | - | - | - | - | - | 158 | ? |
| LP-08 | 98.7 | 2.6 | 94.7-100.0 | 1.3 | 2.6 | 0.0-5.3 | - | - | - | - | - | - | 125 | ? |
| LP-09 | 100.0 | 0.0 | - | - | - | - | - | - | - | - | - | - | 104 | 22 |
| LP-10 | 100.0 | 0.0 | - | - | - | - | - | - | - | - | - | - | 136 | 23 |
| LP-11 | 100.0 | 0.0 | - | - | - | - | - | - | - | - | - | - | 80 | ? |
| LP-12 | 100.0 | 0.0 | - | - | - | - | - | - | - | - | - | - | 101 | 116 |
| LP-13 | 97.5 | 5.0 | 90.0-100.0 | - | - | - | 2.5 | 5.0 | 0.0-10.0 | - | - | - | 130 | ? |
| LP-14 | 100.0 | 0.0 | - | - | - | - | - | - | - | - | - | - | 112 | ? |
| LP-15 | 100.0 | 0.0 | - | - | - | - | - | - | - | - | - | - | 103 | 164 |
| LP-16 | 96.2 | 4.6 | 90.9-100.0 | 3.8 | 4.6 | 0.0-9.1 | - | - | - | - | - | - | 120 | ? |
| LP-17 | 100.0 | 0.0 | - | - | - | - | - | - | - | - | - | - | 88 | ? |
| LP-18 | 100.0 | 0.0 | - | - | - | - | - | - | - | - | - | - | 110 | ? |
| LP-19 | 100.0 | 0.0 | - | - | - | - | - | - | - | - | - | - | 57 | 19 |
| LP-20 | 100.0 | 0.0 | - | - | - | - | - | - | - | - | - | - | 230 | ? |
| LP-21 | 100.0 | 0.0 | - | - | - | - | - | - | - | - | - | - | 102 | ? |
| LP-22 | 100.0 | 0.0 | - | - | - | - | - | - | - | - | - | - | 83 | ? |
| LP-23 | 100.0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 72 | ? |
| LP-24 | 93.4 | -- | -- | 4.4 | -- | -- | -- | -- | -- | 2.2 | -- | -- | 72 | ? |
| LP-25 | 99.7 | -- | -- | -- | -- | -- | -- | -- | -- | 0.3 | -- | -- | 107 | 237 |
| LP-26 | 100.0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 107 | 237 |
| LP-27 | 100.0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 109 | ? |
| LP-28 | 100.0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 109 | ? |

[1]Includes live and dead lodpepole pine stems. The additional tree species mixture was composed of live stems.

[2]All stands owe their present origin to fire.

[3]? = unknown; unable to determine from field evidence in the immediate surrounding area.

[4]Multiple fires.

Table 20.-- *Age and height of dominant trees used for site index determination, crown competition factor, and site index by sampled stand.*

| Stand No. | Dominant Trees: Age (yrs.) $\bar{x}$ | s | Range | Height (ft.) $\bar{x}$ | s | Range | Crown Competition Factor $\bar{x}$ | s | Range | Site Index[1] | Number of Trees |
|---|---|---|---|---|---|---|---|---|---|---|---|
| LP-01 | 85.1 | 2.9 | 80- 89 | 46.0 | 3.1 | 40-49 | 188.2 | 30.6 | 152.1-224.7 | 53.5 | 7 |
| LP-02 | 101.8 | 1.0 | 101-103 | 46.5 | 1.5 | 44-48 | 128.2 | 11.8 | 111.1-137.9 | 46.2 | 6 |
| LP-03 | 100.1 | 2.6 | 97-103 | 34.0 | 3.8 | 30-38 | 368.2 | 39.1 | 329.5-422.6 | 42.4 | 7 |
| LP-04 | 79.2 | 1.7 | 77- 82 | 31.5 | 0.8 | 31-33 | 330.3 | 36.4 | 279.7-362.3 | 44.5 | 6 |
| LP-05 | 74.8 | 1.3 | 73- 76 | 45.0 | 2.3 | 43-48 | 119.0 | 13.7 | 101.9-132.3 | 53.1 | 5 |
| LP-06 | 271.8[2] | 10.6 | 256-282 | 55.2 | 3.1 | 52-59 | 133.1 | 16.2 | 117.8-153.9 | 39.5 | 5 |
| LP-07 | 149.0 | 13.2 | 136-171 | 61.7 | 3.4 | 58-68 | 175.5 | 50.4 | 122.1-234.5 | 52.7 | 6 |
| LP-08 | 120.1 | 4.9 | 110-125 | 57.7 | 4.9 | 51-65 | 135.2 | 23.5 | 115.9-164.9 | 53.0 | 7 |
| LP-09 | 99.3 | 1.5 | 98-101 | 46.8 | 3.7 | 43-53 | 309.6 | 62.8 | 220.3-363.3 | 55.4 | 6 |
| LP-10 | 125.0 | 8.3 | 115-136 | 52.8 | 4.9 | 49-61 | 193.5 | 29.4 | 161.9-224.0 | 49.5 | 5 |
| LP-11 | 78.0 | 1.3 | 76- 80 | 52.3 | 2.2 | 50-56 | 117.0 | 16.7 | 101.3-137.3 | 60.0 | 6 |
| LP-12 | 98.7 | 2.6 | 95-101 | 34.0 | 2.0 | 31-37 | 521.6 | 107.1 | 396.8-656.0 | 50.9 | 6 |
| LP-13 | 124.5 | 4.1 | 118-130 | 40.8 | 4.2 | 37-45 | 225.8 | 26.8 | 205.4-263.1 | 38.8 | 6 |
| LP-14 | 110.2 | 1.5 | 109-112 | 30.0 | 3.7 | 25-35 | 273.6 | 47.6 | 209.9-322.9 | 31.9 | 6 |
| LP-15 | 100.5 | 1.5 | 99-103 | 39.5 | 5.8 | 34-49 | 414.8 | 57.1 | 329.4-449.4 | 51.6 | 6 |
| LP-16 | 111.2 | 5.4 | 106-120 | 68.7 | 3.1 | 64-73 | 138.9 | 16.6 | 117.0-153.7 | 66.0 | 6 |
| LP-17 | 86.0 | 1.1 | 85- 88 | 54.5 | 1.6 | 53-57 | 242.0 | 60.9 | 188.1-307.9 | 65.9 | 6 |
| LP-18 | 101.2 | 6.6 | 91-110 | 30.7 | 3.1 | 27-35 | 406.8 | 88.4 | 312.6-525.0 | 39.6 | 6 |
| LP-19 | 53.5 | 3.3 | 49- 57 | 31.0 | 1.6 | 29-33 | 345.7 | 65.4 | 274.7-402.8 | 62.5 | 4 |
| LP-20 | 219.8[2] | 8.3 | 209-230 | 46.0 | 1.5 | 43-47 | 129.9 | 30.5 | 96.2-165.2 | 31.2 | 6 |
| LP-21 | 101.2 | 1.3 | 99-102 | 45.0 | 5.0 | 41-53 | 154.3 | 28.0 | 127.7-191.0 | 45.8 | 6 |
| LP-22 | 81.3 | 1.9 | 78- 83 | 28.5 | 2.8 | 26-33 | 451.7 | 96.8 | 353.7-585.1 | 45.8 | 6 |
| LP-23 | 70.0 | 1.8 | 68- 72 | 40.8 | 2.8 | 39-46 | 176.5 | - | - | 52.9 | 6 |
| LP-24 | 69.8 | 1.4 | 68- 72 | 33.3 | 1.6 | 32-36 | 258.3 | - | - | 47.4 | 6 |
| LP-25 | 102.1 | 2.1 | 100-105 | 35.7 | 2.9 | 33-41 | 362.1 | - | - | 43.7 | 7 |
| LP-26 | 100.0 | 3.8 | 97-107 | 29.7 | 4.0 | 26-36 | 285.3 | - | - | 34.2 | 6 |
| LP-27 | 107.8 | 1.0 | 106-109 | 30.3 | 0.8 | 29-31 | 283.6 | - | - | 33.0 | 6 |
| LP-28 | 107.7 | 2.0 | 104-109 | 25.3 | 0.8 | 25-27 | 355.6 | - | - | 29.4 | 6 |

[1]At a 100-year base age.

[2]Reduced to 200 years for site index determination because the equations were not based on data including ages over 200 years (see Brickell 1970).

Table 21.-- *Terrain slope, aspect, elevation, physiographic site type, and slope configuration by sampled stand.*

| Stand No. | Terrain Slope (%) x | s | Range | Aspect (deg.) x | Range | Elevation[1] (feet) | Physiographic Site[2] | Slope Configuration[3] |
|---|---|---|---|---|---|---|---|---|
| LP-01 | 16.8 | 5.5 | 10-26 | 153.7 | 120-184 | 9,000 | LS-bench | CC |
| LP-02 | 31.0 | 2.9 | 22-34 | 10.2 | 22-344 | 8,700 | US | S |
| LP-03 | 32.0 | 4.5 | 27-46 | 353.7 | 8-342 | 8,700 | US | S |
| LP-04 | 16.9 | 4.7 | 13-29 | 26.8 | 5- 62 | 8,300 | LS-bench | S |
| LP-05 | 26.6 | 3.6 | 22-33 | 41.8 | 15- 62 | 9,900 | US | CV |
| LP-06 | 6.9 | 2.4 | 4-12 | 58.2 | 22- 77 | 9,100 | US | CC |
| LP-07 | 11.3 | 1.3 | 9-13 | 205.8 | 192-218 | 9,950 | US-bench | S |
| LP-08 | 40.5 | 3.8 | 34-45 | 13.9 | 7- 20 | 9,950 | US | S |
| LP-09 | 30.3 | 1.3 | 28-32 | 102.1 | 100-106 | 8,500 | MS | S |
| LP-10 | 10.3 | 1.8 | 7-13 | 339.9 | 333-345 | 8,450 | MS | S |
| LP-11 | 28.5 | 2.0 | 26-34 | 77.1 | 70- 81 | 8,850 | US | CV |
| LP-12 | 50.0 | 3.2 | 46-56 | 252.0 | 247-255 | 9,800 | US | S |
| LP-13 | 46.1 | 3.5 | 40-52 | 21.5 | 18- 24 | 9,200 | MS | S |
| LP-14 | 25.5 | 2.2 | 21-30 | 130.7 | 127-133 | 9,500 | US | S |
| LP-15 | 13.1 | 0.6 | 12-14 | 274.5 | 266-283 | 9,200 | US | CC |
| LP-16 | 6.8 | 2.1 | 3- 9 | 357.0 | 5-351 | 9,700 | US-bench | S |
| LP-17 | 14.5 | 2.6 | 8-18 | 163.7 | 147-174 | 9,150 | LS | CC |
| LP-18 | 18.5 | 4.4 | 7-25 | 62.3 | 57- 67 | 8,600 | US | U |
| LP-19 | 21.6 | 2.7 | 18-27 | 134.1 | 129-140 | 8,400 | US | S |
| LP-20 | 44.9 | 2.3 | 40-49 | 358.5 | 3-356 | 9,000 | US | S |
| LP-21 | 15.1 | 3.2 | 8-20 | 323.3 | 317-338 | 8,850 | LS | U |
| LP-22 | 23.9 | 1.7 | 22-27 | 24.5 | 19- 27 | 8,400 | US | U |
| LP-23 | 24.0 | 0.0 | 24-24 | 192.0 | 192-192 | 9,950 | US | S |
| LP-24 | 23.0 | 0.0 | 23-23 | 192.0 | 192-192 | 9,950 | US | S |
| LP-25 | 14.0 | 0.0 | 14-14 | 15.0 | 15- 15 | 8,550 | LS-bench | S |
| LP-26 | 10.0 | 0.0 | 10-10 | 15.0 | 15- 15 | 8,550 | LS-bench | S |
| LP-27 | 11.0 | 0.0 | 11-11 | 331.0 | 331-331 | 8,700 | LS-bench | S |
| LP-28 | 11.0 | 0.0 | 11-11 | 321.0 | 321-321 | 8,700 | LS-bench | S |

[1]Taken from U.S. Geological Survey 7.5 minute series (topographic) quadrangle maps to the nearest 50 feet based on the legal description.

[2]LS = lower slope; MS = mid-slope; US = upper slope.

[3]CC = concave/186-355°; S = straight/175-185°; CV = convex/5-175°; U = undulating.

and 34 slides has been assembled into a "photo series" of natural residues and surface fuel conditions typical of even-aged lodgepole pine stands in the eastern Colorado Front Range (Alexander 1978). A summary sheet indicating fuel, stand, and site conditions accompanies a black and white print of each sampled stand. Figures 2 to 9 portray various fuel and stand conditions encountered in field sampling and mentioned in this thesis. Selected notes and observations on sampled stands are included in Appendix C.

## Fuel Loadings and Depths

All plot-by-plot tallied intersections, loading and depth values, and measures of dispersion and central tendency have been documented in a file report by Alexander et al. (1976). Copies of the file report have been deposited in the libraries of Colorado State University and the USDA Forest Service Rocky Mountain Forest and Range Experiment Station. Mean ground and surface fuel descriptors have also been stored as part of the computerized retrieval system of the Natural Forest Fuels Data Bank containing published and unpublished data on natural forest fuel loadings and depths in western conifer stands (Peirce 1977).

Recalculated fuel loadings from Clagg's (1975) study are documented in Table 22. Differences (% difference $= \frac{\text{Recalculated - Clagg}}{\text{Clagg}} \times 100\%$) due to the recalculation of the 0.25-0.99, 1.0-2.99, and 3.0 + sound inch size classes were approximately +12,500, +8900, and -10 percent, respectively. Included in Table 22 from Clagg's study is the duff depth and calculated duff loading. The age, aspect, and elevation of Clagg's stands are also noted for completeness as reference was made to these stands in Chapter 2 and will again be made.

Figure 2.-- *Illustration of needle litter and <0.25 inch size class material (Stand LP-01).*

Figure 3.-- *Illustration of 1.0-2.99 inch size class material resulting from suppression mortality (Stand LP-22).*

Figure 4.-- *Sound material 3.0 inches and greater in diameter resulting from natural mortality (Stand LP-06).*

Figure 5.-- *Rotten material 3.0 inches and greater in diameter resulting from the antecedent fire-killed stand (Stand LP-15).*

Figure 6.-- *Close-up view of scattered plants in the understory of a lodgepole pine stand (Stand LP-12).*

Figure 7.-- *Example of pole/sawtimber stand dominated by Vaccinium spp. (Stand LP-16).*

Figure 8.-- *Example of sapling stand heavily infested with lodgepole pine dwarf mistletoe (Arceuthobium americanum Nutt. ex Engelm.). (Stand LP-26).*

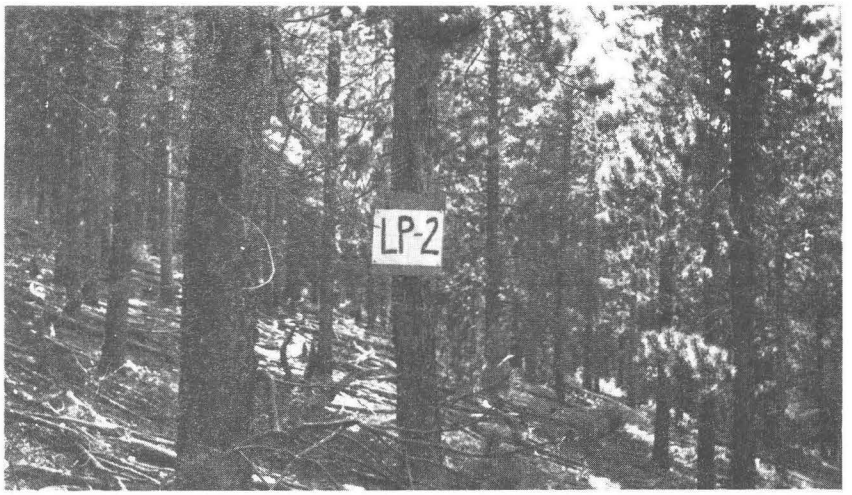



Figure 9.-- *Example of pole/sawtimber stand thinned by Civilian Conservation Corps in the mid-1930's (Stand LP-02).*

Table 22.-- *Selected stand and site characteristics, and ground and surface fuel descriptors for seventeen lodgepole pine stands sampled by Clagg (1975) in Colorado.*

| Stand No. | Age (yrs.) | Aspect (deg.) | Elevation (ft.) | Loading by downed woody size class, T/A | | | | Duff | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 0.25-0.99" | 1.0-2.99" | 3.0"+Rotten | 3.0"+Sound | Depth, in. | Loading, T/A |
| CL-7-3 | 1 | 268 | 8,800 | 0.305 | 0.878 | 0.873 | 12.773 | 0.1 | 1.579 |
| CL-1-3 | 2 | 275 | 8,800 | 0.092 | 0.659 | 0.330 | 9.575 | 0.0 | 0.0 |
| C -5-3 | 8 | 254 | 9,800 | 0.061 | 0.439 | 1.285 | 4.141 | 0.8 | 12.632 |
| C -5-5 | 8 | 127 | 10,040 | 0.0 | 0.0 | 0.0 | 0.561 | 0.0 | 0.0 |
| NF-4-1 | 18 | 181 | 10,030 | 0.488 | 2.196 | 0.0 | 29.020 | 0.4 | 6.316 |
| NF-4-5 | 18 | 126 | 10,020 | 3.724 | 4.391 | 0.0 | 32.459 | 0.1 | 1.579 |
| NF-4-8 | 18 | 142 | 9,320 | 0.611 | 3.952 | 1.643 | 18.598 | 0.1 | 1.579 |
| BF-3-2 | 45 | 248 | 9,720 | 0.611 | 3.952 | 7.164 | 3.509 | 1.1 | 17.370 |
| C -5-4 | 85 | 247 | 9,800 | 0.611 | 1.756 | 23.879 | 8.282 | 0.9 | 14.212 |
| C -5-6 | 85 | 141 | 10,040 | 0.305 | 0.878 | 23.006 | 1.263 | 0.9 | 14.212 |
| TR-6-2 | 108 | 78 | 9,600 | 1.038 | 3.074 | 2.850 | 1.123 | 2.7 | 42.634 |
| BF-3-1 | 115 | 254 | 10,000 | 0.427 | 0.439 | 17.845 | 0.0 | 1.9 | 30.002 |
| NF-4-7 | 190 | 120 | 9,280 | 1.038 | 1.317 | 10.964 | 16.774 | 2.5 | 39.476 |
| NF-4-6 | 248 | 143 | 9,980 | 2.686 | 9.660 | 2.568 | 8.948 | 1.4 | 22.107 |
| CL-1-4 | 251 | 330 | 8,700 | 2.961 | 5.489 | 8.506 | 23.353 | 1.7 | 26.844 |
| TR-6-1 | 257 | 39 | 9,600 | 1.007 | 0.659 | 1.651 | 5.138 | 1.7 | 26.844 |
| NF-4-2 | 370 | 179 | 10,300 | 0.733 | 0.878 | 1.977 | 16.563 | 0.6 | 11.369 |

## Forest Floor

Sampled duff depths and loadings ranged from 0.83 to 2.69 ($\bar{x}$ 1.66) inches and 13 to 42.5 ($\bar{x}$ 26.0) tons per acre respectively (Table 23). Litter loading varied from a low of 0.507 to a high of 2.338 with a mean of 1.437 tons per acre (Table 23).

## Woody Surface Fuels

The loading of individual downed woody surface fuels less than 3.0 inches in diameter is summarized in Table 24. Quantities of twigs less than one-quarter inch in diameter ranged from 0.145 to 0.659 ($\bar{x}$ 0.332) tons per acre. Twigs and branchwood between one-quarter to one inch in diameter ranged from 0.139 to 2.322 ($\bar{x}$ 0.285) tons per acre. Surface fuels between one and three inches in diameter varied from 0.134 to 4.376 ($\bar{x}$ 1.565) tons per acre. Mean cone loading was 1.757 (range: 0.537 - 3.821) tons per acre.

The loading and average intersected diameter of downed rotten and sound material 3.0 inches and greater in diameter is noted in Table 25. The loading of rotten material ranged from zero in three stands to nearly 24 tons per acre with average diameter varying from 3.0 to 9.3 inches. The mean loading was 5.530 tons per acre. Loading of sound material varied from zero in eight stands to a maximum of 7.258 tons per acre. Average diameters ranged from 3.0 to 6.2 inches.

Dead fuel depth varied from 1.65 to 3.81 inches. Mean depth was 2.71 inches (Table 26). Individual plot transect values averaged as high as 14.25 inches.

Table 23.-- *Duff depth and loading of individual forest floor layers by sampled stand.*

| Stand No. | Duff (F & H layers) depth, in. | | | Loading by forest floor component, T/A | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Duff (F & H layers) | | | Litter (L layer) | | |
| | $\bar{x}$ | s | Range | $\bar{x}$ | s | Range | $\bar{x}$ | s | Range |
| LP-01 | 1.14 | 0.62 | 0.35-2.48 | 18.001 | 9.635 | 5.439-38.540 | 1.774 | 0.703 | 0.744- 3.940 |
| LP-02 | 1.08 | 0.57 | 0.30-2.25 | 17.054 | 8.858 | 4.662-34.966 | 1.708 | 0.646 | 0.591- 2.674 |
| LP-03 | 1.62 | 0.76 | 0.50-3.28 | 25,581 | 11.811 | 7.770-50.973 | 1.569 | 0.510 | 0.862- 2.647 |
| LP-04 | 0.83 | 0.72 | 0.28-3.23 | 13.106 | 11.189 | 4.351-50.196 | 1.277 | 0.468 | 0.761- 2.718 |
| LP-05 | 1.32 | 0.76 | 0.40-2.88 | 20.843 | 11.811 | 6.216-44.757 | 1.775 | 0.594 | 0.775- 2.626 |
| LP-06 | 1.60 | 0.79 | 0.30-2.95 | 25.265 | 12.277 | 4.662-45.844 | 1.915 | 0.823 | 0.612- 3.013 |
| LP-07 | 1.23 | 0.27 | 0.73-1.65 | 19.422 | 4.196 | 11.345-25.642 | 1.977 | 0.470 | 1.223- 3.885 |
| LP-08 | 1.79 | 0.41 | 1.33-2.83 | 28.265 | 6.372 | 20.669-43.980 | 2.031 | 0.649 | 1.178- 3.674 |
| LP-09 | 1.59 | 0.39 | 1.05-2.25 | 25.107 | 6.061 | 16.318-34.966 | 2.042 | 0.497 | 1.321- 2.920 |
| LP-10 | 1.53 | 0.47 | 0.73-2.33 | 24.159 | 7.304 | 11.345-36.209 | 1.744 | 0.613 | 0.925- 3.409 |
| LP-11 | 1.69 | 0.73 | 0.53-3.28 | 26.686 | 11.345 | 8.236-50.973 | 1.453 | 0.835 | 0.419- 3.122 |
| LP-12 | 2.69 | 1.17 | 0.85-5.63 | 42.476 | 18.182 | 13.209-87.493 | 1.069 | 0.450 | 0.452- 2.252 |
| LP-13 | 2.10 | 0.75 | 1.05-3.73 | 33.160 | 11.655 | 16.318-57.966 | 2.234 | 0.556 | 1.317- 3.684 |
| LP-14 | 1.43 | 0.34 | 0.90-2.00 | 22.580 | 5.284 | 13.986-31.081 | 1.008 | 0.233 | 0.691- 1.370 |
| LP-15 | 2.58 | 0.68 | 1.58-3.70 | 40.739 | 10.568 | 24.554-57.450 | 1.168 | 0.290 | 0.657- 1.774 |
| LP-16 | 2.38 | 0.69 | 1.40-4.03 | 37.581 | 10.723 | 21.757-62.628 | 1.103 | 0.288 | 0.543- 1.754 |
| LP-17 | 2.12 | 1.03 | 0.88-5.05 | 33.476 | 16.007 | 13.676-78.480 | 2.104 | 0.452 | 1.360- 3.111 |
| LP-18 | 2.02 | 0.55 | 1.28-3.28 | 31.897 | 8.547 | 19.892-50.973 | 1.456 | 0.477 | 0.923- 2.899 |
| LP-19 | 1.19 | 0.68 | 0.08-2.63 | 18.791 | 10.568 | 1.243-40.872 | 1.315 | 0.510 | 0.474- 2.403 |
| LP-20 | 1.60 | 0.59 | 0.78-2.83 | 25.265 | 9.169 | 12.122-43.980 | 1.512 | 0.870 | 0.764- 4.365 |
| LP-21 | 1.75 | 0.67 | 0.65-2.98 | 27.633 | 10.412 | 10.101-46.311 | 0.860 | 0.371 | 0.342- 1.444 |
| LP-22 | 1.86 | 0.69 | 1.03-3.00 | 29.370 | 10.723 | 16.007-46.622 | 1.422 | 0.686 | 0.649- 3.279 |
| LP-23 | 1.10 | 0.62 | 0.48-2.08 | 17.370 | 9.635 | 7.459-32.324 | 0.722 | 0.203 | 0.504- 0.965 |
| LP-24 | 1.11 | 0.24 | 0.93-1.50 | 17.527 | 3.730 | 14.453-23.311 | 0.507 | 0.265 | 0.419- 1.133 |
| LP-25 | 1.59 | 0.63 | 0.85-2.60 | 25.107 | 9.791 | 13.209-40.405 | 0.884 | 0.336 | 0.596- 1.447 |
| LP-26 | 2.00 | 0.77 | 0.93-3.03 | 31.581 | 11.966 | 14.453-47.088 | 0.716 | 0.426 | 0.287- 1.422 |
| LP-27 | 1.73 | 0.76 | 1.10-3.00 | 27.318 | 11.811 | 17.095-46.622 | 1.420 | 0.390 | 0.938- 1.984 |
| LP-28 | 1.72 | 0.70 | 0.90-2.73 | 27.160 | 10.878 | 13.987-42.426 | 1.363 | 0.484 | 0.885- 2.073 |

Table 24.-- *Loading of downed woody surface fuels < 3.0 inches in diameter by sampled stand.*

| Stand No. | Loading by downed woody size class, T/A | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | <0.25" | | | 0.25-0.99" | | | 1.0-2.99" | | | Cones | | |
| | $\bar{x}$ | s | Range | $\bar{x}$ | s | Range | $\bar{x}$ | s | Range | $\bar{x}$ | s | Range |
| LP-01 | 0.167 | 0.105 | 0.022-0.503 | 0.331 | 0.334 | 0.0 -1.046 | 0.439 | 0.841 | 0.0 - 2.507 | 1.524 | 1.724 | 0.0 - 6.277 |
| LP-02 | 0.183 | 0.134 | 0.044-0.586 | 0.775 | 0.450 | 0.176-1.937 | 4.322 | 2.312 | 0.0 - 9.118 | 3.140 | 2.962 | 0.0 - 9.964 |
| LP-03 | 0.224 | 0.112 | 0.033-0.435 | 0.663 | 0.613 | 0.0 -2.131 | 1.090 | 0.982 | 0.0 - 3.065 | 2.679 | 1.672 | 0.0 - 5.480 |
| LP-04 | 0.309 | 0.118 | 0.087-0.481 | 0.557 | 0.330 | 0.0 -1.044 | 0.334 | 0.489 | 0.0 - 1.001 | 1.074 | 0.969 | 0.0 - 3.581 |
| LP-05 | 0.145 | 0.094 | 0.033-0.362 | 0.361 | 0.333 | 0.0 -1.048 | 0.201 | 0.564 | 0.0 - 2.011 | 1.258 | 0.307 | 0.0 - 4.495 |
| LP-06 | 0.263 | 0.148 | 0.054-0.630 | 1.396 | 1.803 | 0.173-7.442 | 0.598 | 1.543 | 0.0 - 5.975 | 3.087 | 2.328 | 0.0 - 8.013 |
| LP-07 | 0.311 | 0.134 | 0.054-0.588 | 0.913 | 0.595 | 0.173-2.081 | 0.665 | 0.722 | 0.0 - 1.995 | 3.627 | 1.921 | 0.0 - 6.244 |
| LP-08 | 0.175 | 0.076 | 0.090-0.338 | 0.311 | 0.276 | 0.0 -0.898 | 0.207 | 0.428 | 0.0 - 1.034 | 3.821 | 3.404 | 0.0 -14.791 |
| LP-09 | 0.504 | 0.131 | 0.220-0.749 | 1.767 | 1.050 | 0.526-4.212 | 4.376 | 3.654 | 0.0 -12.118 | 2.107 | 2.405 | 0.0 - 8.126 |
| LP-10 | 0.443 | 0.143 | 0.217-0.674 | 1.535 | 0.907 | 0.520-3.983 | 3.255 | 2.211 | 0.0 - 8.968 | 2.311 | 1.710 | 0.0 - 7.127 |
| LP-11 | 0.165 | 0.082 | 0.077-0.330 | 0.187 | 0.243 | 0.0 -0.876 | 0.134 | 0.355 | 0.0 - 1.008 | 1.443 | 1.266 | 0.0 - 4.508 |
| LP-12 | 0.401 | 0.144 | 0.184-0.655 | 0.879 | 0.311 | 0.366-1.648 | 1.545 | 1.186 | 0.0 - 4.214 | 1.821 | 1.725 | 0.0 - 5.652 |
| LP-13 | 0.247 | 0.101 | 0.023-0.437 | 0.391 | 0.338 | 0.0 -0.916 | 0.773 | 1.159 | 0.0 - 3.161 | 2.449 | 2.822 | 0.0 -11.304 |
| LP-14 | 0.300 | 0.092 | 0.154-0.496 | 1.030 | 0.720 | 0.351-3.159 | 1.751 | 1.595 | 0.0 - 5.049 | 0.843 | 0.868 | 0.0 - 2.709 |
| LP-15 | 0.380 | 0.169 | 0.120-0.689 | 1.486 | 1.095 | 0.174-3.832 | 2.405 | 1.355 | 0.0 - 4.009 | 1.015 | 1.008 | 0.0 - 2.688 |
| LP-16 | 0.359 | 0.160 | 0.022-0.565 | 0.243 | 0.215 | 0.0 -0.520 | 0.864 | 1.547 | 0.0 - 5.980 | 0.713 | 0.839 | 0.0 - 2.673 |
| LP-17 | 0.659 | 0.240 | 0.153-0.939 | 0.800 | 0.371 | 0.0 -1.392 | 1.535 | 2.202 | 0.0 - 7.007 | 2.088 | 1.381 | 0.0 - 4.475 |
| LP-18 | 0.549 | 0.234 | 0.230-0.921 | 1.013 | 0.606 | 0.0 -2.271 | 2.279 | 2.357 | 0.0 - 9.048 | 2.097 | 1.581 | 0.0 - 5.393 |
| LP-19 | 0.197 | 0.122 | 0.044-0.440 | 0.199 | 0.310 | 0.0 -1.227 | 0.404 | 0.638 | 0.0 - 2.018 | 0.902 | 0.762 | 0.0 - 1.804 |
| LP-20 | 0.330 | 0.130 | 0.135-0.528 | 0.835 | 0.564 | 0.0 -1.967 | 3.842 | 2.038 | 1.029- 8.233 | 1.779 | 1.573 | 0.0 - 5.520 |
| LP-21 | 0.180 | 0.103 | 0.033-0.393 | 0.417 | 0.359 | 0.0 -1.217 | 3.736 | 4.530 | 0.0 -17.010 | 1.252 | 0.944 | 0.0 - 3.578 |
| LP-22 | 0.276 | 0.079 | 0.099-0.407 | 1.427 | 0.735 | 0.877-2.807 | 1.076 | 1.234 | 0.0 - 4.038 | 1.023 | 1.016 | 0.0 - 2.708 |
| LP-23 | 0.183 | 0.115 | 0.066-0.342 | 0.141 | 0.147 | 0.0 -0.351 | 0.404 | 0.554 | 0.0 - 1.011 | 1.265 | 1.030 | 0.0 - 2.711 |
| LP-24 | 0.153 | 0.088 | 0.055-0.251 | 0.139 | 0.146 | 0.0 -0.348 | 1.603 | 1.820 | 0.0 - 4.007 | 0.537 | 0.801 | 0.0 - 1.791 |
| LP-25 | 0.582 | 0.131 | 0.425-0.752 | 1.181 | 0.450 | 0.695-1.737 | 3.998 | 2.737 | 1.000- 7.996 | 1.787 | 1.264 | 0.0 - 2.681 |
| LP-26 | 0.657 | 0.238 | 0.391-1.022 | 2.322 | 1.265 | 0.016-3.292 | 1.196 | 0.834 | 0.0 - 1.994 | 1.070 | 1.062 | 0.0 - 2.674 |
| LP-27 | 0.283 | 0.066 | 0.196-0.381 | 0.278 | 0.436 | 0.0 -1.042 | 0.200 | 0.447 | 0.0 - 0.999 | 1.250 | 1.495 | 0.0 - 3.573 |
| LP-28 | 0.413 | 0.137 | 0.207-0.576 | 1.524 | 0.553 | 0.866-2.251 | 0.598 | 0.546 | 0.0 - 0.996 | 1.247 | 1.351 | 0.0 - 2.673 |

Table 25.-- *Loading and average diameter of downed rotten and sound material ≥ 3.0 inches in diameter by sampled stand.*

| Stand No. | 3.0" + size class loading, T/A | | | | | | 3.0" + diameters, in. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rotten | | | Sound | | | Rotten | | | | Sound | | | | Sound & Rotten | |
| | $\bar{x}$ | s | Range | $\bar{x}$ | s | Range | $\bar{x}$ | s | Range | n | $\bar{x}$ | s | Range | n | $\bar{x}$ | s |
| LP-01 | 17.076 | 10.475 | 3.448-39.128 | 5.646 | 10.085 | 0.0 -42.511 | 6.9 | 2.5 | 3-16 | 90 | 6.0 | 2.8 | 3-17 | 27 | 6.7 | 2.6 |
| LP-02 | 7.057 | 4.266 | 0.640-12.156 | 0.175 | 0.490 | 0.0 1.749 | 4.1 | 1.8 | 3-12 | 74 | 3.0 | 0.0 | 3-3 | 3 | 4.1 | 1.8 |
| LP-03 | 8.325 | 4.536 | 1.147-15.842 | 0.0 | -- | -- | 5.5 | 1.7 | 3-10 | 52 | -- | -- | -- | 0 | 5.5 | 1.7 |
| LP-04 | 0.267 | 0.570 | 0.0 - 1.757 | 0.730 | 1.662 | 0.0 - 6.146 | 4.3 | 0.6 | 4-5 | 3 | 5.0 | 2.2 | 3-8 | 4 | 4.7 | 1.6 |
| LP-05 | 6.655 | 5.434 | 0.0 -19.894 | 2.937 | 6.308 | 0.0 -24.200 | 5.4 | 1.7 | 3-10 | 45 | 4.8 | 2.5 | 3-10 | 16 | 5.2 | 1.9 |
| LP-06 | 5.716 | 5.194 | 0.0 -14.814 | 7.258 | 10.790 | 0.0 -37.627 | 5.9 | 2.2 | 3-14 | 31 | 6.2 | 3.1 | 3-15 | 24 | 6.0 | 2.6 |
| LP-07 | 1.003 | 2.403 | 0.0 - 7.000 | 0.319 | 1.021 | 0.0 - 3.923 | 5.8 | 3.4 | 3-10 | 5 | 4.0 | 1.0 | 3-5 | 3 | 5.1 | 2.8 |
| LP-08 | 5.964 | 6.061 | 0.0 -18.500 | 0.165 | 0.455 | 0.0 - 0.586 | 6.6 | 2.5 | 3-11 | 25 | 3.5 | 0.7 | 7-4 | 2 | 6.4 | 2.5 |
| LP-09 | 0.043 | 0.165 | 0.0 - 0.368 | 0.103 | 0.400 | 0.0 - 1.549 | 3.0 | 0.0 | 3-3 | 1 | 4.0 | 0.0 | 4-4 | 1 | 3.5 | 0.7 |
| LP-10 | 0.149 | 0.394 | 0.0 - 1.119 | 1.975 | 1.805 | 0.0 - 6.211 | 4.0 | 0.0 | 4-4 | 2 | 3.7 | 1.0 | 3-7 | 21 | 3.7 | 1.0 |
| LP-11 | 7.487 | 6.019 | 0.0 -18.965 | 0.335 | 0.957 | 0.0 - 3.482 | 6.7 | 2.1 | 3-11 | 32 | 5.0 | 1.4 | 4-6 | 2 | 6.6 | 2.1 |
| LP-12 | 5.589 | 5.591 | 0.0 -14.195 | 0.472 | 1.105 | 0.0 - 3.637 | 5.8 | 2.1 | 3-14 | 30 | 4.7 | 1.5 | 3-6 | 3 | 5.7 | 2.0 |
| LP-13 | 7.152 | 5.934 | 0.0 - 18.557 | 0.600 | 1.687 | 0.0 - 6.467 | 5.3 | 1.8 | 3-9 | 46 | 5.0 | 2.7 | 3-8 | 3 | 5.3 | 1.8 |
| LP-14 | 0.463 | 1.793 | 0.0 - 6.945 | 0.174 | 0.489 | 0.0 - 1.743 | 7.0 | 0.0 | 7-7 | 2 | 3.0 | 0.0 | 3-3 | 2 | 5.0 | 2.3 |
| LP-15 | 23.805 | 8.515 | 11.603-44.512 | 0.218 | 0.644 | 0.0 - 2.403 | 6.1 | 1.6 | 3-11 | 127 | 4.0 | 1.4 | 3-5 | 2 | 6.1 | 1.7 |
| LP-16 | 5.460 | 7.949 | 0.0 -23.500 | 0.159 | 0.617 | 0.0 - 2.390 | 7.9 | 2.5 | 3-13 | 17 | 5.0 | 0.0 | 5-5 | 1 | 7.8 | 2.5 |
| LP-17 | 0.918 | 1.624 | 0.0 - 4.917 | 0.422 | 0.781 | 0.0 - 2.400 | 4.1 | 1.5 | 3-7 | 9 | 3.8 | 0.8 | 3-5 | 6 | 4.0 | 1.3 |
| LP-18 | 0.0 | -- | -- | 0.0 | -- | -- | -- | -- | -- | 0 | -- | -- | -- | - | -- | -- |
| LP-19 | 0.042 | 0.165 | 0.0 - 0.637 | 0.0 | -- | -- | 3.0 | 0.0 | 3-3 | 1 | -- | -- | -- | 0 | 3.0 | 0.0 |
| LP-20 | 0.944 | 1.173 | 0.0 - 4.188 | 6.698 | 3.668 | 0.888-12.237 | 3.9 | 1.4 | 3-7 | 11 | 4.0 | 1.0 | 3-9 | 61 | 4.0 | 1.0 |
| LP-21 | 1.816 | 1.933 | 0.0 - 6.881 | 0.729 | 1.716 | 0.0 - 6.141 | 4.6 | 1.4 | 3-7 | 17 | 6.0 | 1.7 | 5.8 | 3 | 4.8 | 1.5 |
| LP-22 | 5.124 | 4.565 | 0.0 -13.104 | 0.161 | 0.625 | 0.0 - 2.420 | 5.4 | 2.1 | 3-12 | 33 | 5.0 | 0.0 | 5-5 | 1 | 5.4 | 2.0 |
| LP-23 | 12.886 | 12.178 | 4.154-32.823 | 0.0 | -- | -- | 7.3 | 4.4 | 4-18 | 9 | -- | -- | -- | 0 | 7.3 | 4.4 |
| LP-24 | 22.554 | 22.557 | 9.941-62.560 | 0.0 | -- | -- | 6.5 | 2.0 | 3-11 | 24 | -- | -- | -- | 0 | 6.5 | 2.0 |
| LP-25 | 0.0 | -- | -- | 0.0 | -- | -- | -- | -- | -- | 0 | -- | -- | -- | - | -- | -- |
| LP-26 | 0. 0 | -- | -- | 0.0 | -- | -- | -- | -- | -- | 0 | -- | -- | -- | - | -- | -- |
| LP-27 | 3.285 | 4.675 | 0.0 -10.014 | 1.314 | 1.199 | 0.0 - 2.190 | 9.0 | 1.4 | 8-10 | 2 | 4.0 | 0.0 | 4.4 | 3 | 6.0 | 2.8 |
| LP-28 | 5.048 | 3.913 | 0.0 -10.069 | 0.0 | -- | -- | 9.3 | 2.5 | 6-12 | 4 | -- | -- | -- | 0 | 9.3 | 2.5 |

Table 26.-- *Dead and live fuel depth, loading of dead and live understory vegetation, and date inventoried by sampled stand.*

| Stand No. | Fuel depth, in. | | | | | | Understory vegetation loading, T/A | | | | | | Date Int.[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dead | | | Live | | | Dead | | | Live | | | |
| | $\bar{x}$ | s | Range | $\bar{x}$ | s | Range | $\bar{x}$ | s | Range | $\bar{x}$ | s | Range | |
| LP-01 | 1.73 | 0.67 | 1.17- 3.90 | 0.38 | 0.53 | 0.0 -1.50 | 0.0031 | 0.0083 | 0.0 -0.0372 | 0.0196 | 0.0699 | 0.0 -0.3160 | 06-23 |
| LP-02 | 2.29 | 1.08 | 1.42- 5.83 | 0.33 | 0.51 | 0.0 -1.50 | 0.0031 | 0.0081 | 0.0 -0.0316 | 0.0127 | 0.0226 | 0.0 -0.0865 | 06-25 |
| LP-03 | 1.65 | 0.30 | 1.00- 2.25 | 0.11 | 0.19 | 0.0 -0.58 | 0.0001 | 0.0002 | 0.0 -0.0007 | 0.0016 | 0.0020 | 0.0 -0.0068 | 06-26 |
| LP-04 | 1.76 | 0.83 | 1.17- 4.50 | 0.06 | 0.15 | 0.0 -0.50 | 0.0002 | 0.0003 | 0.0 -0.0011 | 0.0025 | 0.0056 | 0.0 -0.0224 | 06-30 |
| LP-05 | 2.06 | 0.40 | 1.33- 2.67 | 2.57 | 1.39 | 0.08-4.83 | 0.0140 | 0.0162 | 0.0 -0.0592 | 0.1657 | 0.1134 | 0.0002-0.4733 | 07-02 |
| LP-06 | 2.93 | 2.59 | 1.17-10.00 | 0.22 | 0.31 | 0.0 -0.83 | 0.0028 | 0.0043 | 0.0 -0.0153 | 0.0148 | 0.0220 | 0.0 -0.0671 | 07-08 |
| LP-07 | 3.24 | 2.58 | 1.67-12.33 | 3.96 | 1.49 | 1.25-6.17 | 0.0341 | 0.0311 | 0.0031-0.1067 | 0.2799 | 0.1479 | 0.1152-0.6122 | 07-16 |
| LP-08 | 2.50 | 0.56 | 1.67- 3.83 | 4.54 | 0.71 | 3.33-5.83 | 0.0976 | 0.0808 | 0.0098-0.3010 | 0.4844 | 0.1576 | 0.2111-0.7913 | 07-18 |
| LP-09 | 3.47 | 1.59 | 1.75- 7.83 | 0.59 | 0.47 | 0.0 -1.33 | 0.0004 | 0.0004 | 0.0 -0.0013 | 0.0089 | 0.0089 | 0.0 -0.0279 | 07-22 |
| LP-10 | 3.79 | 3.07 | 2.17-14.25 | 1.56 | 1.03 | 0.0 -4.08 | 0.0092 | 0.0093 | 0.0 -0.0290 | 0.0522 | 0.0412 | 0.0015-0.1392 | 07-23 |
| LP-11 | 2.73 | 1.15 | 1.67- 6.50 | 3.77 | 2.08 | 0.0 -7.17 | 0.0678 | 0.0679 | 0.0 -0.2753 | 0.3913 | 0.3289 | 0.0024-1.2403 | 07-27 |
| LP-12 | 3.30 | 2.25 | 1.83-10.83 | 0.72 | 0.81 | 0.0 -3.08 | 0.0013 | 0.0018 | 0.0 -0.0048 | 0.0131 | 0.0195 | 0.0 -0.0734 | 08-05 |
| LP-13 | 2.29 | 0.39 | 1.80- 3.33 | 0.18 | 0.33 | 0.0 -0.92 | 0.0044 | 0.0158 | 0.0 -0.0614 | 0.0119 | 0.0357 | 0.0 -0.1401 | 08-07 |
| LP-14 | 2.37 | 0.79 | 1.75- 4.42 | 0.16 | 0.0 | - | 0.0030 | 0.0050 | 0.0 -0.0078 | 0.0084 | 0.0126 | 0.0 -0.0357 | 08-12 |
| LP-15 | 3.15 | 1.34 | 1.83- 6.25 | 0.55 | 0.72 | 0.0 -2.42 | 0.0034 | 0.0065 | 0.0 -0.0244 | 0.0189 | 0.0229 | 0.0 -0.0817 | 08-19 |
| LP-16 | 3.81 | 0.82 | 2.58- 5.33 | 7.35 | 1.37 | 4.67-9.75 | 0.2340 | 0.1180 | 0.0884-0.4051 | 0.8162 | 0.3807 | 0.1880-1.4797 | 08-24 |
| LP-17 | 2.59 | 0.71 | 1.58- 4.08 | 0.41 | 0.46 | 0.0 -1.42 | 0.0064 | 0.0042 | 0.0 -0.0115 | 0.0221 | 0.0309 | 0.0013-0.0900 | 08-26 |
| LP-18 | 2.93 | 1.43 | 1.67- 7.42 | 0.22 | 0.42 | 0.0 -1.25 | 0.0003 | 0.0006 | 0.0 -0.0017 | 0.0021 | 0.0021 | 0.0 -0.0072 | 08-28 |
| LP-19 | 2.66 | 1.29 | 1.50- 6.75 | 2.94 | 2.65 | 0.0 -8.42 | 0.0504 | 0.0443 | 0.0017-0.1448 | 0.1456 | 0.1366 | 0.0068-0.4225 | 09-02 |
| LP-20 | 3.05 | 0.91 | 2.08- 5.67 | 1.23 | 1.00 | 0.0 -3.00 | 0.0409 | 0.0487 | 0.0 -0.1387 | 0.1214 | 0.1286 | 0.0 -0.4093 | 09-04 |
| LP-21 | 2.20 | 0.53 | 1.42- 3.25 | 0.43 | 0.70 | 0.0 -2.50 | 0.0218 | 0.0277 | 0.0 -0.0867 | 0.0832 | 0.0989 | 0.0 -0.2912 | 09-09 |
| LP-22 | 2.87 | 1.12 | 1.83- 4.92 | 0.19 | 0.36 | 0.0 -1.25 | 0.0010 | 0.0016 | 0.0 -0.0048 | 0.0048 | 0.0068 | 0.0 -0.0237 | 09-15 |
| LP-23 | 2.23 | 0.69 | 1.50- 3.25 | 0.97 | 1.17 | 0.0 -2.92 | 0.0412 | 0.0543 | 0.0002-0.1324 | 0.0781 | 0.0805 | 0.0011-0.1910 | 09-19 |
| LP-24 | 2.38 | 0.48 | 1.92- 2.83 | 1.63 | 0.64 | 0.75-2.25 | 0.0365 | 0.0152 | 0.0126-0.0525 | 0.0710 | 0.0323 | 0.0309-0.1146 | 09-20 |
| LP-25 | 3.38 | 2.12 | 2.00- 7.08 | 0.37 | 0.51 | 0.0 -1.08 | 0.0110 | 0.0161 | 0.0 -0.0388 | 0.0170 | 0.0233 | 0.0002-0.0573 | 09-21 |
| LP-26 | 3.28 | 0.83 | 2.33- 4.33 | 0.15 | 0.15 | 0.0 -0.33 | 0.0014 | 0.0028 | 0.0 -0.0063 | 0.0095 | 0.0161 | 0.0 -0.0379 | 09-22 |
| LP-27 | 2.07 | 0.45 | 1.42- 2.67 | 0.22 | 0.48 | 0.0 -1.08 | 0.0097 | 0.0100 | 0.0 -0.0231 | 0.0332 | 0.0362 | 0.0 -0.0823 | 09-22 |
| LP-28 | 3.17 | 1.02 | 2.50- 4.92 | 0.33 | 0.37 | 0.0 -0.90 | 0.0602 | 0.1105 | 0.0 -0.2546 | 0.1112 | 0.2001 | 0.0 -0.4624 | 09-22 |

[1]Month and day that the vegetation was sampled in the stand. Reference year is 1975.

## Understory Vegetation

Live fuel depth ranged from zero to 7.35 ($\bar{x}$ 1.29) inches (Table 26). Dead and live understory vegetations weights ranged from 0.001 to 0.2340 ($\bar{x}$ 0.1072) tons per acre, respectively (Table 26). The quantity of dead understory vegetation ranged from 3.2 to 39.3 and averaged 19.0 percent. The dates on which understory vegetation weights were sampled are contained in Table 26 for completeness.

## Fuel Sampling Error

Overall, the sampling intensities of the < 0.25 inch size class and litter loading, duff depth, and dead fuel depth were sufficient to furnish percent errors of twenty percent or less in estimating the grand means although variation between stand means is apparent (Table 27). Except for the 0.25-0.99 inch size class and cones, the resulting percent errors are in fact a function of natural individual inter-stand rather than intra-stand variation. It is not surprising that downed rotten and sound material 3.0 inches and greater in diameter had such high variation.

## Crown Fuels and Stem Bole

Individual crown fuel component and stem bole weights are contained in Table 28. The crown fuel loadings should only be considered as *conservative* because the percentage of intermediate and suppressed trees was ocularly estimated rather than denoted for each individual count tree in the timber plot sampling. Estimated crown bulk densities are noted in Table 28 as well. The distribution of stems by D.B.H. size classes, and percentages of the two crown class groups are documented in Appendix D.

Table 27.-- *Mean and range of percent errors of individual fuel loading and depth descriptors by number of plots per stand.*

| Fuel Component | | Stand LP-01 [20 plots] | Stands LP-02 to 22 [15 plots/stand] | Stands LP-23 to 28 [5 plots/stand] | Stands LP-01 to 28 [5,15 or 20 plots/stand] |
|---|---|---|---|---|---|
| | | | percent | | |
| <0.25" size class | $\overline{SE}_{\bar{x}}$ | 14 | 11.6 | 17.5 | 12.9 |
| | Range | - | 7-19 | 10-28 | 7-28 |
| 0.25-0.99" size class | $\overline{SE}_{\bar{x}}$ | 23 | 20.2 | 36.8 | 23.9 |
| | Range | - | 9-40 | 16-70 | 9-70 |
| 1.0-2.99" size class | $\overline{SE}_{\bar{x}}$ | 43 | 34.6 | 52.5 | 38.8 |
| | Range | - | 14-72 | 31-100 | 14-100 |
| 3.0" + rotten size class | $\overline{SE}_{\bar{x}}$ | 14 | 42.2 | 46.5 | 41.8 |
| | Range | - | 9-100 | 35-45 | 9-100 |
| 3.0" + sound size class | $\overline{SE}_{\bar{x}}$ | 40 | 63.6 | 41.0 | 61.3 |
| | Range | - | 14-100 | - | 14-100 |
| cones | $\overline{SE}_{\bar{x}}$ | 25 | 22.2 | 46.7 | 27.5 |
| | Range | - | 9-30 | 32-53 | 9-53 |
| litter | $\overline{SE}_{\bar{x}}$ | 9 | 11.9 | 18.0 | 13.1 |
| | Range | - | 6-32 | 12-27 | 6-32 |
| dead understory vegetation | $\overline{SE}_{\bar{x}}$ | 80 | 31.5 | 55.3 | 38.4 |
| | Range | - | 8-80 | 20-80 | 8-80 |
| live understory vegetation | $\overline{SE}_{\bar{x}}$ | 59 | 38.1 | 59.2 | 43.4 |
| | Range | - | 13-92 | 19-85 | 13-92 |
| duff depth | $\overline{SE}_{\bar{x}}$ | 12 | 10.9 | 18.0 | 12.5 |
| | Range | - | 6-22 | 10-25 | 6-25 |
| live fuel depth | $\overline{SE}_{\bar{x}}$ | 32 | 29.7 | 54.5 | 35.3 |
| | Range | - | 4-65 | 18-98 | 4-98 |
| dead fuel depth | $\overline{SE}_{\bar{x}}$ | 9 | 11.0 | 14.5 | 11.7 |
| | Range | - | 4-23 | 9-28 | 4-28 |

Table 28.-- *Loading of crown fuels and stem bole, and crown bulk density by sampled stand.*

| Stand No. | Loading by Crown Fuel Component, T/A | | | | Stem Bole[2] (T/A) | Crown Bulk Density[3] (lb./ft$^3$) |
|---|---|---|---|---|---|---|
| | | Branchwood[1] by Size Class | | | | |
| | Foliage | <0.25" | 0.25-0.99" | 1.0-2.99" | | |
| LP-01 | 4.32 | 3.23 | 3.63 | 0.38 | 35.4 | 0.013 |
| LP-02 | 3.05 | 2.39 | 2.92 | 0.49 | 24.4 | 0.006 |
| LP-03 | 4.54 | 3.04 | 2.86 | 0.07 | 22.1 | 0.033 |
| LP-04 | 4.25 | 2.93 | 2.85 | 0.09 | 25.5 | 0.030 |
| LP-05 | 2.76 | 2.13 | 2.53 | 0.53 | 23.1 | 0.006 |
| LP-06 | 4.31 | 3.50 | 4.36 | 1.97 | 55.1 | 0.009 |
| LP-07 | 6.50 | 5.05 | 6.08 | 1.57 | 70.4 | 0.014 |
| LP-08 | 4.02 | 3.18 | 3.97 | 0.90 | 41.3 | 0.008 |
| LP-09 | 4.25 | 2.96 | 2.94 | 0.12 | 40.9 | 0.022 |
| LP-10 | 5.38 | 4.08 | 4.72 | 0.66 | 48.7 | 0.013 |
| LP-11 | 3.11 | 2.48 | 3.17 | 0.78 | 31.7 | 0.004 |
| LP-12 | 6.80 | 4.56 | 4.28 | 0.09 | 37.7 | 0.045 |
| LP-13 | 5.68 | 4.32 | 5.02 | 0.64 | 46.6 | 0.014 |
| LP-14 | 5.59 | 3.86 | 3.82 | 0.15 | 19.0 | 0.039 |
| LP-15 | 5.41 | 3.66 | 3.51 | 0.11 | 49.1 | 0.032 |
| LP-16 | 4.59 | 3.61 | 4.45 | 1.24 | 52.9 | 0.008 |
| LP-17 | 4.68 | 3.47 | 3.85 | 0.38 | 58.4 | 0.012 |
| LP-18 | 5.38 | 3.71 | 3.64 | 0.14 | 29.8 | 0.035 |
| LP-19 | 7.80 | 5.63 | 5.96 | 0.38 | 33.3 | 0.027 |
| LP-20 | 3.45 | 2.47 | 2.55 | 0.14 | 33.4 | 0.011 |
| LP-21 | 3.70 | 2.80 | 3.21 | 0.38 | 28.1 | 0.009 |
| LP-22 | 5.36 | 3.54 | 3.26 | 0.05 | 21.5 | 0.038 |
| LP-23 | 3.50 | 2.68 | 3.15 | 0.44 | 27.0 | 0.008 |
| LP-24 | 4.31 | 3.05 | 3.11 | 0.16 | 19.4 | 0.016 |
| LP-25 | 4.61 | 3.10 | 2.94 | 0.07 | 39.1 | 0.026 |
| LP-26 | 2.95 | 1.92 | 1.74 | 0.03 | 9.9 | 0.021 |
| LP-27 | 5.31 | 3.79 | 3.93 | 0.24 | 22.0 | 0.023 |
| LP-28 | 3.69 | 2.42 | 2.21 | 0.03 | 9.2 | 0.031 |

[1]Includes live and dead crown material for live stems only. Dead stems assumed to have no significant amount.

[2]Includes standing live and dead stem material. A certain portion of the bole weight will include 1.0-2.99 inch size class, especially in stands having a small D.B.H.

[3]Crown bulk density (lb./ft$^3$) = foliage weight (lb./ft$^2$) ÷ live crown length (ft.) (Van Wagner 1977).

## Fuel Complex Characterization

### Stylized Stand Habit

The separation of stand according to their stylized habit resulted in 14 sapling and 14 pole/sawtimber stands. Pertinent stand structure characteristics associated with the stylized stand habits are presented in Table 29.

The mean and range of ground and surface fuel descriptors of all sampled stands and by stylized stand habit are reported in Table 30. Results of the $t$ tests are noted in Table 31. Loading of sound material >3.0 inches in diameter, cones, and live understory vegetation, live fuel depth, and distance to live crown base were significantly different between sapling and pole/sawtimber stands at the 0.050 level or better. Loading of <0.25 and 0.25-0.99 inch size classes, litter, and total understory vegetation were significantly different at the 0.100 level or better.

The mean and range of crown fuel descriptors and stem bole of all stands and by stylized stand habit are documented in Table 32. Results of the $t$ tests are noted in Table 33. The <0.25 and 0.25-0.99 inch size classes were the only descriptors not significant at even the 0.100 level.

### Component and Strata Percentages

The percentages by weight of individual fuel components and fuel complex stratas of all stands and by stylized stand habit are noted in tables 34, 35, and 36. On the average, duff comprised nearly 70 percent by weight of the combined and ground/surface fuel stratas while surface fuels < 3.0 (including cones, litter, and understory vegetation) and

Table 29.-- *Selected stand structure parameters associated with stylized stand habits.*

| Stand Structure Characteristic | Sapling Stands | Pole/Sawtimber Stands | All Stands |
|---|---|---|---|
| Live Stem Density, #/A | 3552 | 582 | 2067 |
| Dead Stem Density, #/A[1] | 936 | 65 | 501 |
| Live Stem Height, ft. | 21 | 41 | 31 |
| Live Stem D.B.H., in. | 2.7 | 7.2 | 5.0 |
| Dead Stem D.B.H. in.[2] | 1.7 | 6.0 | 3.4 |

[1]Values are based on the calculation of all stands within a group including those possessing no dead stems.

[2]Values are based on the calculation of only stands possessing dead stems.

Table 30.-- *Ground and surface fuel descriptors by stylized stand habit.*

| Fuel Descriptor | | Sapling Stands | Pole/Sawtimber Stands | All Stands |
|---|---|---|---|---|
| | | - - - - - - - - - - T/A - - - - - - - - - - - - | | |
| Loading | | | | |
| < 0.25" size class | $\bar{x}$ | 0.373 | 0.272 | 0.322 |
| | Range | 0.153-0.657 | 0.145-0.659 | 0.145-0.659 |
| 0.25-0.99" size class | $\bar{x}$ | 1.033 | 0.617 | 0.825 |
| | Range | 0.139-2.322 | 0.187-1.535 | 0.139-2.322 |
| 1.0-2.99" size class | $\bar{x}$ | 1.633 | 1.498 | 1.565 |
| | Range | 0.200-4.376 | 0.134-4.323 | 0.134-4.376 |
| 3.0" + rotten size class | $\bar{x}$ | 5.325 | 5.735 | 5.530 |
| | Range | 0.0-23.305 | 0.149-17.076 | 0.0-23.305 |
| 3.0" + sound size class | $\bar{x}$ | 0.227 | 1.958 | 1.093 |
| | Range | 0.0-1.314 | 0.0-7.258 | 0.0-7.258 |
| cones | $\bar{x}$ | 1.284 | 2.123 | 1.757 |
| | Range | 0.537-2.679 | 0.713-3.821 | 0.537-3.821 |
| litter | $\bar{x}$ | 1.230 | 1.637 | 1.437 |
| | Range | 0.507-2.042 | 0.722.2.338 | 0.507-2.338 |
| duff | $\bar{x}$ | 27.024 | 25.299 | 26.161 |
| | Range | 13.106-42.476 | 17.054-37.581 | 13.106-42.476 |
| dead understory vegetation | $\bar{x}$ | 0.0128 | 0.0415 | 0.0272 |
| | Range | 0.0001-0.0602 | 0.0028-0.2340 | 0.0001-0.2340 |
| live understory vegetation | $\bar{x}$ | 0.0332 | 0.1823 | 0.1072 |
| | Range | 0.0016-0.1456 | 0.0119-0.8162 | 0.0016-0.8162 |
| total understory vegetation | $\bar{x}$ | 0.0400 | 0.2239 | 0.1320 |
| | Range | 0.0017-0.1960 | 0.0158-1.0502 | 0.0017-1.0502 |
| | | - - - - - - - - - - in. - - - - - - - - - - - - | | |
| Depths | | | | |
| duff depth | $\bar{x}$ | 1.71 | 1.60 | 1.66 |
| | Range | 0.83-2.69 | 1.08-2.38 | 0.83-2.69 |
| live fuel depth | $\bar{x}$ | 0.58 | 1.99 | 1.29 |
| | Range | 0.0-2.94 | 0.18-7.35 | 0.0-7.35 |
| dead fuel depth | $\bar{x}$ | 2.75 | 2.67 | 2.71 |
| | Range | 1.65-3.47 | 1.73-3.81 | 1.65-3.81 |
| | | - - - - - - - - - - ft. - - - - - - - - - - - - | | |
| Distance to Live Crown Base | $\bar{x}$ | 13.0 | 19.9 | 16.4 |
| | Range | 6.3-23.5 | 11.0-30.8 | 6.3-30.8 |
| 3.0" + Size Class Diameters | | - - - - - - - - - - in. - - - - - - - - - - - - | | |
| rotten[1] | $\bar{x}$ | 5.9 | 5.6 | 5.7 |
| | Range | 3.0-9.3 | 3.9-7.9 | 3.0-9.3 |
| sound[1] | $\bar{x}$ | 4.2 | 4.6 | 4.5 |
| | Range | 3.0-5.0 | 3.0-6.2 | 3.0-6.2 |

[1]Values are based on the calculation of only stands possessing either rotten or sound material.

Table 31.-- *Results of "t" tests on ground and surface fuel descriptors between stylized stand habits.*

| Fuel descriptor | t Statistic | Significance Level |
|---|---|---|
| < 0.25" size class loading | 1.813 | 0.090 |
| 0.25-0.99" size class loading | 2.011 | .060 |
| 1.0-2.99" size class loading | 0.249 | < .500 |
| 3.0" + rotten size class loading | 0.163 | < .500 |
| 3.0" + sound size class loading | 2.443 | .025 |
| cone loading | 2.917 | .008 |
| litter loading | 2.542 | .020 |
| duff loading | 0.627 | < .500 |
| dead understory vegetation loading | 1.640 | .150 |
| live understory vegetation loading | 2.338 | .030 |
| total understory vegetation loading | 2.010 | .060 |
| duff depth | 0.627 | < .500 |
| live fuel depth | 2.294 | .035 |
| dead fuel depth | 0.306 | < .500 |
| distance to live crown base | 3.197 | .005 |
| 3.0" + rotten size class average diameter (n=23)[1] | 0.433 | < .500 |
| 3.0" + sound size class average diameter (n=18) | 0.854 | < .400 |

[1]n = 26 unless otherwise noted.

Table 32.-- *Crown fuel descriptors and stem bole loading by stylized stand habit.*

| Fuel Descriptor | | Sapling Stands | Pole/Sawtimber Stands | All Stands |
|---|---|---|---|---|
| | | - - - - - - - - - T/A - - - - - - - - - - - - - - - | | |
| Loading | | | | |
| foliage | $\bar{x}$ | 5.02 | 4.22 | 4.62 |
| | Range | 2.95-7.80 | 2.76-650 | 2.76-7.80 |
| <0.25 inch size class | $\bar{x}$ | 3.44 | 3.24 | 3.34 |
| | Range | 1.92-5.63 | 2.13-5.05 | 1.92-5.63 |
| 0.25-0.99 inch size class | $\bar{x}$ | 3.36 | 3.83 | 3.60 |
| | Range | 1.74-5.96 | 2.53-6.08 | 1.74-6.08 |
| 1.0-2.99 inch size class | $\bar{x}$ | 0.12 | 0.75 | 0.44 |
| | Range | 0.03-0.38 | 0.14-1.97 | 0.03-1.97 |
| stem bole | $\bar{x}$ | 27.0 | 41.2 | 34.1 |
| | Range | 9.2-49.1 | 23.1-58.4 | 9.2-58.4 |
| | | - - - - - - - - - lb./ft.$^3$ - - - - - - - - - - - - - - - | | |
| Crown Bulk Density | $\bar{x}$ | 0.030 | 0.010 | 0.020 |
| | Range | 0.021-0.045 | 0.004-0.014 | 0.004-0.045 |

Table 33.-- *Results of "t" tests on crown fuel descriptors between stylized stand habits.*

| Fuel Descriptor [1] | *t* Statistic | Significance Level |
|---|---|---|
| foliage loading | 1.823 | 0.090 |
| <0.25" size class loading | 0.602 | < .500 |
| 0.25-0.99" size class loading | 1.227 | .250 |
| 1.0-2.99" size class loading | 4.484 | .001 |
| bole loading | 2.833 | .010 |
| crown bulk density | 8.806 | .001 |

[1] n = 26.

Table 34.-- *Percent by weight of individual ground and surface fuels with duff (w/d) and without duff (w/o d) included by stylized stand habit.*

| Fuel Component | Sapling Stands | | Pole/Sawtimber Stands | | All Stands | |
|---|---|---|---|---|---|---|
| | percent[1] | | | | | |
| | w/d | w/o d | w/d | w/o d | w/d | w/o d |
| <0.25" size class | 1.0 | 3.4 | 0.7 | 1.9 | 0.8 | 2.5 |
| 0.25-0.99" size class | 2.7 | 9.3 | 1.6 | 4.4 | 2.1 | 6.4 |
| 1.0-2.99" size class | 4.3 | 14.7 | 3.8 | 10.7 | 4.0 | 12.2 |
| 3.0" + rotten size class | 14.0 | 47.8 | 14.6 | 40.8 | 14.3 | 43.1 |
| 3.0" + sound size class | 0.6 | 2.0 | 5.0 | 13.9 | 3.0 | 9.0 |
| cones | 3.4 | 11.5 | 5.4 | 15.1 | 4.5 | 13.7 |
| litter | 3.2 | 11.0 | 4.2 | 11.6 | 4.0 | 12.0 |
| duff | 70.8 | -- | 64.3 | -- | 66.9 | -- |
| understory vegetation | 0.1 | 0.4 | 0.6 | 1.6 | 0.3 | 1.0 |

[1]Rounding errors may cause the percentages to total around 100.

Table 35.-- *Percent by weight of individual crown fuels and stem bole as a portion of the total aerial fuel strata with bole (w/b) and without bole (w/o b) included by stylized stand habit.*

| Fuel Component | Sapling Stands | | Pole/Sawtimber Stands | | All Stands | |
|---|---|---|---|---|---|---|
| | percent[1] | | | | | |
| | w/b | w/o b | w/b | w/o b | w/b | w/o b |
| foliage | 12.9 | 42.0 | 7.9 | 35.1 | 10.0 | 38.5 |
| < 0.25 inch size class | 8.8 | 28.8 | 6.1 | 26.9 | 7.3 | 27.8 |
| 0.25-0.99 inch size class | 8.6 | 28.1 | 7.2 | 31.8 | 7.8 | 30.0 |
| 1.0-2.99 inch size class | 0.3 | 1.0 | 1.4 | 6.2 | 1.0 | 3.7 |
| stem bole | 69.3 | -- | 77.4 | -- | 74.0 | -- |

[1]Rounding errors may cause the percentages to total around 100.

Table 36.-- *Percent by weight of individual fuel complex stratas as a portion of the total fuel complex with stem bole included (w/b), without stem bole (w/o b) and with foliage considered as the aerial fuel (f) by stylized stand habit.*

| Fuel Complex Strata | Sapling Stands | | | Pole/Sawtimber Stands | | | All Stands | | |
|---|---|---|---|---|---|---|---|---|---|
| | percent[1] | | | | | | | | |
| | w/b | w/o b | f | w/b | w/o b | f | w/b | w/o b | f |
| Ground (duff) | 43.3 | 62.3 | 70.2 | 36.9 | 60.1 | 68.3 | 39.8 | 61.2 | 69.2 |
| Surface | 12.6 | 18.2 | 20.5 | 13.2 | 21.5 | 24.4 | 13.0 | 19.9 | 22.6 |
| Aerial (total) | 44.1 | 19.5 | -- | 49.9 | 18.4 | -- | 47.2 | 18.9 | -- |
| Aerial (foliage only) | -- | -- | 9.2 | -- | -- | 7.3 | -- | -- | 8.2 |

[1]Rounding errors may cause the percentages to total around 100.

$\geq$ 3.0 inches in diameter comprised approximately 16 and 18 percent, respectively (Table 34). If only the surface fuel strata is considered, surface fuels < 3.0 and $\geq$ 3.0 inches in diameter shared nearly equivalent percentages.

Nearly three-quarters of the total aerial fuel strata was composed of the stem bole with foliage making-up 10 percent and woody fuels the remainder (Table 35). Foliage comprised nearly 39 percent of the total crown fuels by weight.

The ground, surface, and aerial stratas comprised approximately 40, 13, and 47 percent, respectively, of the total fuel complex (Table 36). If the stem bole component is excluded from the aerial strata, the ground surface stratas constituted nearly 61 and 20 percent, respectively. If only foliage is considered in the aerial strata, the ground strata contributed 70 percent and the surface strata 23 percent.

## Vegetation Classification

The mean and range of ground and surface fuel descriptors by vegetation division and type/phase are noted in Tables 37, 38, and 39. Each vegetation classification level represents units of similar biological potential. Real differences in ground and surface fuel loadings (Tables 37 and 38) between divisions or even type/phases were difficult to extinguish because of an insufficient number of stands. Obvious differences were more apparent when viewing live fuel depth and understory vegetation (Table 39).

Table 37.-- *Loading of individual downed woody surface fuels by vegetation divisions and types/phases.*

| Code Name[1] | | Loading by downed woody size class, T/A | | | | | | Number of Stands |
|---|---|---|---|---|---|---|---|---|
| | | <0.25" | 0.25-0.99" | 1.0-2.99" | 3.0"+ rotten | 3.0"+ sound | cones | |
| ARUV | $\bar{x}$ | 0.348 | 0.910 | 1.276 | 3.685 | 1.491 | 1.558 | 11 |
| | Range | 0.167-0.582 | 0.199-2.322 | 0.200-3.998 | 0.042-17.076 | 0.0 -5.646 | 0.843-2.679 | |
| CAGE/BERE | $\bar{x}$ | 0.263 | 1.396 | 0.598 | 5.716 | 7.258 | 3.087 | 1 |
| SHCA | $\bar{x}$ | 0.323 | 0.754 | 2.040 | 5.927 | 1.193 | 1.581 | 10 |
| | Range | 0.145-0.659 | 0.187-1.487 | 0.134-4.323 | 0.0 -23.805 | 0.0 -6.698 | 0.713-3.140 | |
| SHCA/VACC | $\bar{x}$ | 0.252 | 0.302 | 0.533 | 6.058 | 1.548 | 0.986 | 2 |
| | Range | 0.145-0.359 | 0.243-0.361 | 0.201-0.864 | 5.460-6.655 | 0.159-2.937 | 0.713-1.258 | |
| SHCA/PYVI/PINUS | $\bar{x}$ | 0.346 | 1.086 | 2.374 | 7.686 | 0.277 | 1.347 | 4 |
| | Range | 0.180-0.549 | 0.417-1.486 | 1.076-3.736 | 0.0 -23.805 | 0.0 -0.729 | 1.015-2.097 | |
| SHCA/JUCO/PINUS | $\bar{x}$ | 0.334 | 0.649 | 2.459 | 4.102 | 1.908 | 2.113 | 4 |
| | Range | 0.165-0.659 | 0.187-0.835 | 0.134-4.323 | 0.918-7.487 | 0.335-6.698 | 1.443-3.140 | |
| VACC | $\bar{x}$ | 0.206 | 0.376 | 0.720 | 10.602 | 0.121 | 2.313 | 4 |
| | Range | 0.153-0.311 | 0.139-0.913 | 0.207-1.603 | 1.003-22.554 | 0.0 -0.319 | 0.537-3.821 | |
| VACC/PYVI | $\bar{x}$ | 0.216 | 0.398 | 0.891 | 12.148 | 0.319 | 1.810 | 3 |
| | Range | 0.153-0.311 | 0.139-0.913 | 0.404-1.603 | 1.003-22.554 | 0.0 -0.319 | 0.537-3.627 | |
| VACC/ARCO/VACC | $\bar{x}$ | 0.175 | 0.311 | 0.207 | 5.964 | 0.165 | 3.821 | 1 |
| **** | $\bar{x}$ | 0.453 | 1.323 | 2.961 | 2.816 | 0.288 | 3.928 | 2 |
| | Range | 0.401-0.504 | 0.879-1.767 | 1.545-4.376 | 0.043-5.589 | 0.103-0.472 | 1.821-2.107 | |

[1] Refer to Table 13 for description of code names.

Table 38.-- *Loading of individual forest floor layers, dead and live understory vegetation, duff depth, and dead fuel depth by vegetation divisions and types/phases.*

| Code Name[1] | | Forest Floor Loading, T/A | | Herbaceous Vegetation Loading, T/A | | Duff Depth, in. | Dead Fuel Depth, in. | Number of Stands |
|---|---|---|---|---|---|---|---|---|
| | | litter (L layer) | duff (F & H layers) | dead | live | | | |
| ARUV | $\bar{x}$ | 1.401 | 24.231 | 0.0139 | 0.0375 | 1.53 | 2.56 | 11 |
| | Range | 0.716-2.338 | 13.106-33.160 | 0.0001-0.0602 | 0.0016-0.1456 | 0.83-2.10 | 1.65-3.79 | |
| CAGE/BERE | $\bar{x}$ | 1.915 | 25.265 | 0.0028 | 0.0148 | 1.60 | 2.93 | 1 |
| SHCA | $\bar{x}$ | 1.456 | 29.055 | 0.0393 | 0.1638 | 1.84 | 2.77 | 10 |
| | Range | 0.860-2.104 | 17.054-40.739 | 0.0003-0.2340 | 0.0021-0.8162 | 1.08-2.58 | 2.06-3.81 | |
| SHCA/VACC | $\bar{x}$ | 1.439 | 29.212 | 0.1240 | 0.4910 | 1.85 | 2.94 | 2 |
| | Range | 1.103-1.775 | 20.843-37.581 | 0.0140-0.2340 | 0.1657-0.8162 | 1.32-2.38 | 2.06-3.81 | |
| SHCA/PYVI/PINUS | $\bar{x}$ | 1.227 | 32.410 | 0.0066 | 0.0273 | 2.05 | 2.79 | 4 |
| | Range | 0.860-1.456 | 27.633-40.739 | 0.0003-0.0218 | 0.0021-0.0832 | 1.75-2.58 | 2.20-3.15 | |
| SHCA/JUCO/PINUS | $\bar{x}$ | 1.694 | 25.870 | 0.0296 | 0.1369 | 1.62 | 2.67 | 4 |
| | Range | 1.453-2.104 | 17.054-33.476 | 0.0031-0.0678 | 0.0127-0.3913 | 1.08-2.12 | 2.29-3.05 | |
| VACC | $\bar{x}$ | 1.309 | 23.502 | 0.0524 | 0.2284 | 1.31 | 2.59 | 4 |
| | Range | 0.507-2.031 | 17.370-37.581 | 0.0341-0.0976 | 0.0710-0.4844 | 1.10-1.79 | 2.23-3.24 | |
| VACC/PYVI | $\bar{x}$ | 1.069 | 18.106 | 0.0373 | 0.1430 | 1.15 | 2.62 | 3 |
| | Range | 0.507-1.977 | 17.370-19.422 | 0.0341-0.0412 | 0.0710-0.2799 | 1.10-1.23 | 2.23-3.24 | |
| VACC/ARCO/VACC | $\bar{x}$ | 2.031 | 28.265 | 0.0976 | 0.4844 | 1.79 | 2.50 | 1 |
| **** | $\bar{x}$ | 1.556 | 33.792 | 0.0024 | 0.0110 | 2.14 | 3.39 | 2 |
| | Range | 1.069-2.042 | 25.107-42.476 | 0.0013-0.0035 | 0.0089-0.0131 | 1.59-2.69 | 3.30-3.47 | |

[1] Refer to Table 13 for description of code names.

Table 39.-- *Live fuel depth and total understory vegetation loading by vegetation divisions and types/phases.*

| Code Name[1] | | Live Fuel Depth (in.) | Herbaceous Vegetation[2] Loading (T/A) | Number of Stands |
|---|---|---|---|---|
| ARUV | $\bar{x}$ | 0.57 | 0.0514 | 11 |
| | Range | 0.0-2.94 | 0.0017-0.1960 | |
| CAGE | $\bar{x}$ | 0.22 | 0.0176 | 1 |
| | Range | | | |
| SHCA | $\bar{x}$ | 1.71 | 0.2031 | 10 |
| | Range | 0.19-7.35 | 0.0024-1.0502 | |
| SHCA/VACC | $\bar{x}$ | 4.96 | 0.6150 | 2 |
| | Range | 2.57-7.35 | 0.1797-1.0502 | |
| SHCA/PYVI/PINUS | $\bar{x}$ | 0.35 | 0.0339 | 4 |
| | Range | 0.19-0.55 | 0.0024-0.1050 | |
| SHCA/JUCO/PINUS | $\bar{x}$ | 1.44 | 0.1664 | 4 |
| | Range | 0.33-3.77 | 0.0158-0.4591 | |
| VACC | $\bar{x}$ | 2.78 | 0.2807 | 4 |
| | Range | 0.97-4.54 | 0.1075-0.5820 | |
| VACC/PYVI | $\bar{x}$ | 2.19 | 0.1803 | 3 |
| | Range | 0.97-3.96 | 0.1075-0.3140 | |
| VACC/ARCO/VACC | $\bar{x}$ | 4.54 | 0.5820 | 1 |
| **** | $\bar{x}$ | 0.66 | 0.0134 | 2 |
| | Range | 0.59-0.72 | 0.0124-0.0144 | |

[1] Refer to Table 13 for description of code names.

[2] Includes live and dead material.

Fuel Prediction

Scatter diagrams of fuel quantities as a function of time since last fire are of almost universal interest in fuel succession discussions. The assumption is that the various age classes are the simultaneous representation of the same stand at different ages. The loading of fine surface fuels (< 0.25 inch size class and litter) versus stand age is depicted in Figure 10. Downed woody surface fuels between one-quarter and three inches in diameter as a function of stand age is illustrated in Figure 11. The loading of downed rotten and sound material $\geq$ 3.0 inches in diameter was also plotted against stand age (Fig. 12). Data from Clagg (1975) is presented in Figures 11 and 12 because his sampled stands lie within the present study area. The scatter diagrams presented in Figures 10-12 graphically illustrate a high degree of dispersion when sampled stands are obtained on a survey basis and included together regardless of stand and site characteristics.

Simple correlation coefficients (r) between independent and dependent variables are presented in Table 40. At n-1 degrees of freedom, r values greater than $\pm$ .367 and .470 are significant at the 0.005 and 0.001 level, respectively, with the dependent variables. An examination of the r matrix (Table 40) revealed a tendency for higher r values when dead stem characteristics where compared against surface fuels $\leq$ 3.0 inches diameter, 3.0+ inch sound size class, and dead fuel depth. On the other hand, cones, litter, duff and understory vegetation, and live fuel depth, duff depth, and distance to live crown base exhibited the opposite effect. Rotten material 3.0 inches and greater in diameter showed no correlation with either live or dead stem characteristics. Stands LP-02 and LP-21 were excluded from the 1.0-2.99 inch size class

Figure 10.-- *Loading of downed woody surface fuels ≤ 0.25 inches in diameter and litter as a function of stand age.*

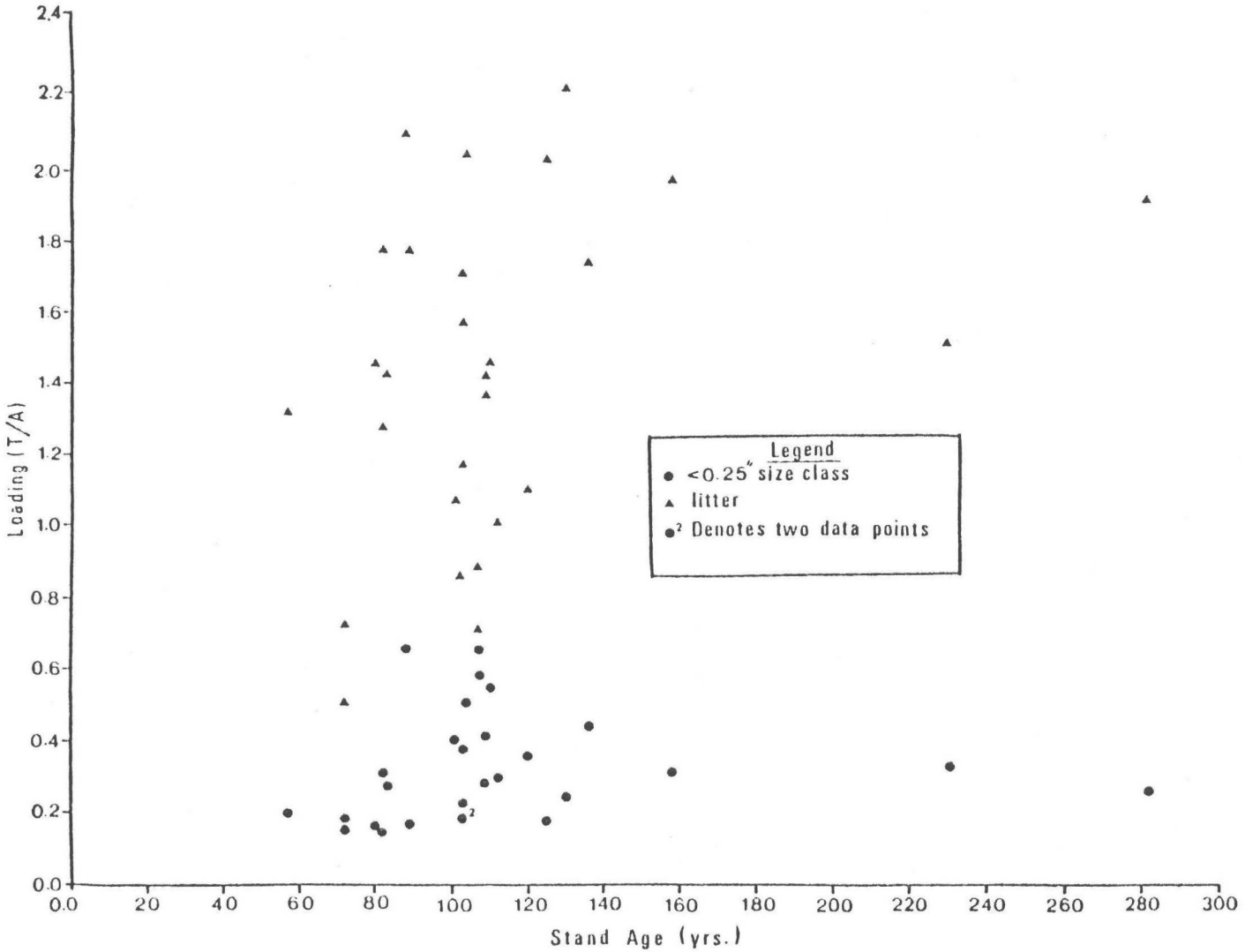


Figure 11.-- *Loading of downed woody surface fuels between 0.25-0.99 and 1.0-2.99 inches in diameter as a function of stand age from the present study and Clagg (1975).*

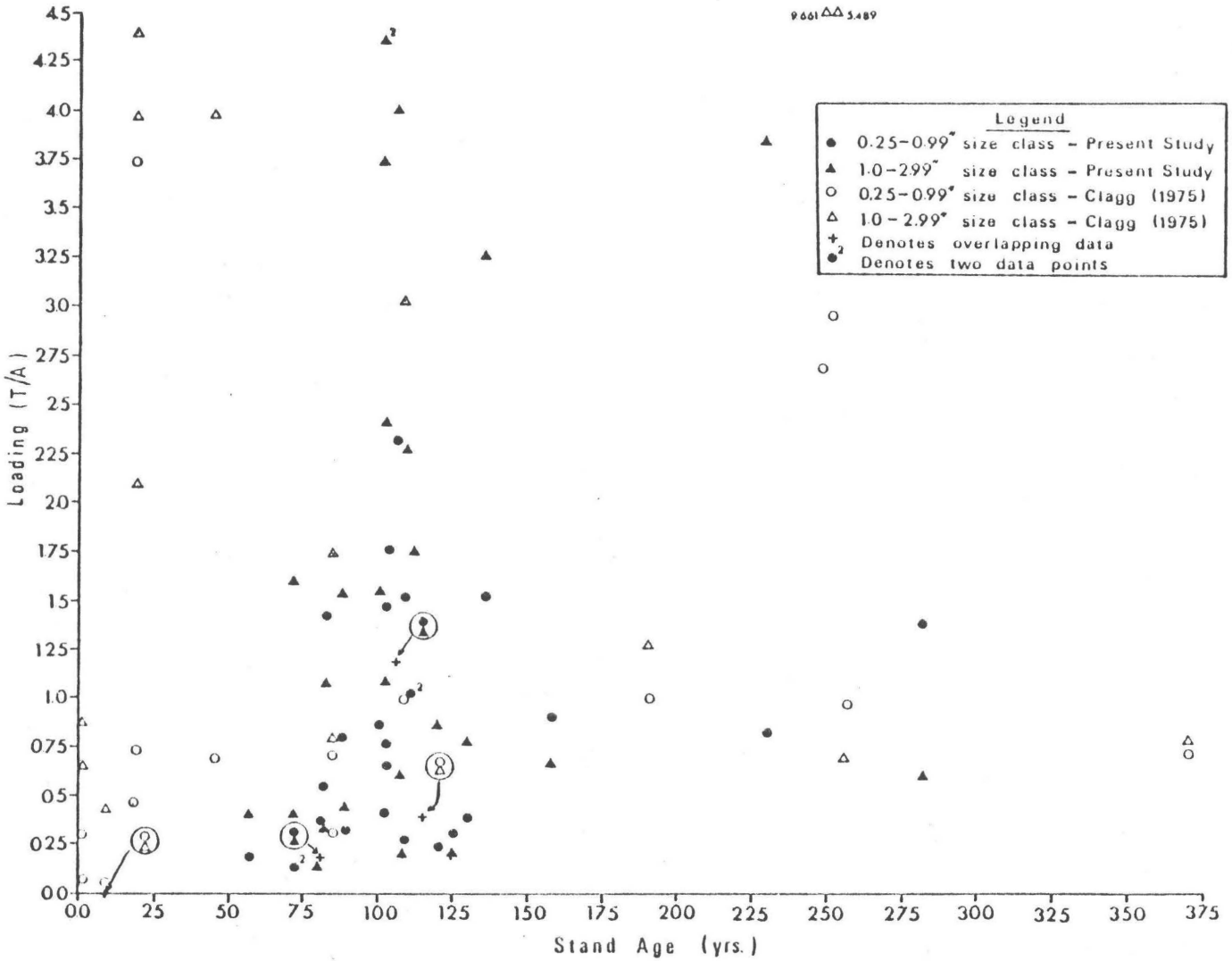


Figure 12.-- *Loading of downed rotten and sound material ≥ in diameter as a function of stand age from the present study and Clagg (1975).*

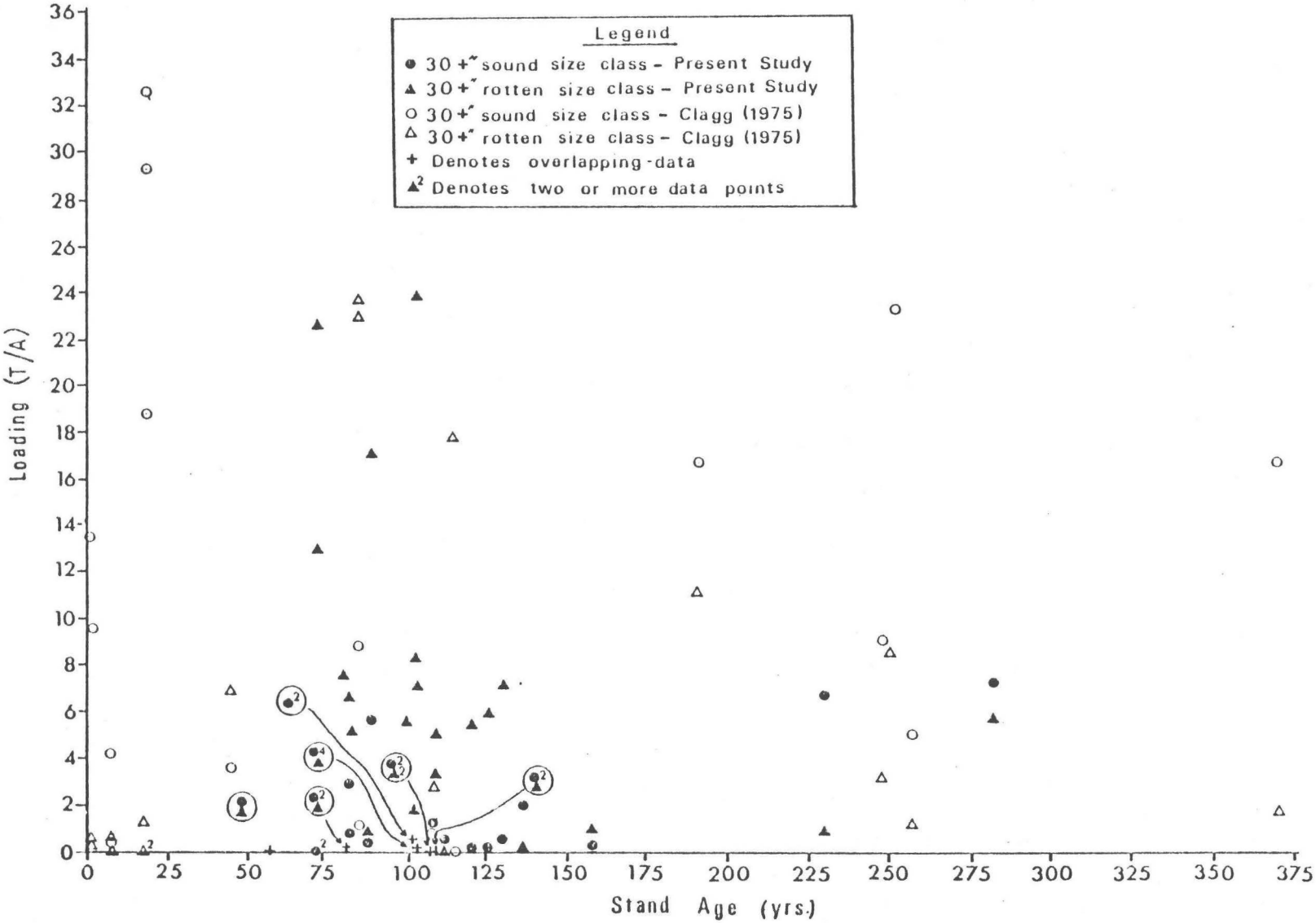


Table 40.-- *Matrix of simple correlation coefficients (r) among independent ($X_i$, stand and site characteristics) and dependent ($Y_i$, fuel descriptors) variables. Values greater than ± .367 and .470 are significant at the 0.005 and 0.001 levels, respectively.*

| Independent Variables | Dependent Variables | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Y(01) <0.25" size class loading | Y(02) 0.25-0.99" size class loading | Y(03) 1.0-2.99" size class loading | Y(04) 3.0"+ rotten size class loading | Y(05) 3.0"+ sound size class loading | Y(06) cone loading | Y(07) litter loading | Y(08) duff loading | Y(09) dead fuel depth | Y(10) live fuel depth | Y(11) duff depth | Y(12) understory vegetation loading | Y(13) distance to live crown base |
| Live Stem BA/A, X(01) | .221 | .002 | .064 | -.046 | -.154 | .172 | .267 | .339 | .202 | -.039 | .339 | -.163 | .246 |
| Dead Stem BA/A, X(02) | .428 | .556 | .634 | -.208 | .539 | .137 | .142 | .178 | .324 | -.373 | .178 | -.357 | .144 |
| Live Stem D/A, X(03) | .424 | .481 | .214 | -.011 | -.406 | -.304 | -.347 | .378 | .166 | -.455 | .378 | -.418 | -.446 |
| Dead Stem D/A, X(04) | .669 | .680 | .416 | -.199 | -.276 | -.152 | -.277 | .260 | .373 | -.382 | .260 | -.301 | -.291 |
| Live Stem Spac., X(05) | -.459 | -.385 | -.281 | .029 | .461 | .375 | .347 | -.184 | -.021 | .566 | -.184 | .551 | .431 |
| Dead Stem Spac., X(06) | -.430 | -.475 | -.328 | .164 | -.174 | -.070 | -.247 | -.121 | -.078 | .439 | -.121 | .509 | .068 |
| Live Stem Vol./A, X(07) | .076 | -.142 | -.010 | -.087 | .119 | .514 | .577 | .194 | .311 | .470 | .194 | .365 | .821 |
| Dead Stem Vol./A, X(08) | .184 | .370 | .498 | -.141 | .754 | .283 | .306 | .079 | .257 | -.215 | .079 | -.226 | .304 |
| Live Stem Ht., X(09) | -.169 | -.296 | -.061 | -.043 | .293 | .470 | .475 | .022 | .217 | .653 | .022 | .609 | .799 |
| Dead Stem Ht., X(10) | .060 | .158 | .166 | -.114 | .479 | .537 | .613 | -.017 | .058 | .018 | -.017 | -.120 | .424 |
| Live Stem DBH, X(11) | -.392 | -.356 | -.283 | -.003 | .461 | .479 | .461 | -.123 | -.052 | .578 | -.123 | .539 | .563 |
| Dead Stem DBH, X(12) | -.175 | -.005 | -.094 | -.081 | .550 | .464 | .546 | -.124 | -.029 | .190 | -.124 | .062 | .306 |
| CCF, X(13) | .413 | .374 | .233 | .008 | -.419 | -.279 | -.279 | .374 | .144 | -.443 | .374 | -.445 | -.379 |
| Site Index, X(14) | -.099 | -.369 | -.135 | .163 | -.201 | .014 | .172 | .056 | .122 | .596 | .056 | .471 | .432 |
| Stand Age, X(15) | .074 | .289 | .209 | -.199 | .704 | .483 | .337 | .101 | .293 | -.010 | .101 | .027 | .430 |
| Elevation, X(16) | -.337 | -.419 | -.285 | .414 | .017 | .115 | -.055 | .089 | -.042 | .466 | .089 | .415 | .280 |
| Terrain Slope, X(17) | -.295 | -.263 | .096 | .050 | -.003 | .244 | .205 | .104 | -.216 | -.045 | .104 | -.076 | -.069 |
| Live Stem $DBH^2$·Ht., X(18) | -.280 | -.229 | -.289 | -.040 | .393 | .468 | .413 | -.017 | .197 | .659 | -.017 | .636 | .601 |
| Live Stem DBH· Ht., X(19) | -.273 | -.287 | -.235 | -.042 | .365 | .486 | .446 | -.022 | .184 | .675 | -.022 | .648 | .678 |
| Dead Stem $DBH^2$·Ht., X(20) | -.270 | -.078 | -.201 | -.037 | .448 | .477 | .456 | -.097 | -.048 | .306 | -.097 | .228 | .226 |
| Dead Stem DBH· Ht., X(21) | -.206 | -.029 | -.110 | -.076 | .518 | .549 | .543 | -.098 | .005 | .271 | -.098 | .170 | .372 |

[1]Does not include stands LP-02 and LP-21. Values of r greater than ± .381 and .487 are significant at the 0.005 and 0.001 levels, respectively.

because these two stands had been thinned by the Civilian Conservation Corps *ca.* 1934-5. This resulted in an abnormal and "unnatural" amount of fuel in this class.

Simple correlation coefficients (r) among independent variables for all stands are contained in Table 41. At n-1 degrees of freedom, r values greater than $\pm$ .367 and .470 are significant at the 0.005 and 0.001 levels, respectively (Snedecor and Cochran 1967, p. 557). Correlation among independent variables for all stands except LP-02 and LP-21, is noted in Table 42. At n-1 degrees of freedom, r values greater than $\pm$ .381 and .487 are significant at the 0.005 and 0.001 levels, respectively. As would be expected, correlations among many independent variables were generally significant. This factor reduced the number of variable regression combinations that could be tested. The highest correlations were among D.B.H., height, (or permutations of D.B.H. and height), density, and spacing.

Models

Equations and pertinent statistics for the regressions developed are summarized in Table 43. All equations have F ratios significant at the 99.5 percent level. The *t* values for all regression coefficients are less than 0.009. Full statistics (analysis of variance, *t* test of regression coefficients, etc.) for all regressions are contained in Appendix E.

Dead stem density was found to be the single most highly correlated independent variable with the < 0.25 and 0.25-0.99 inch size classes (r values of 0.699 and 0.680, respectively). The addition of live stem volume in the former size class greatly improved the overall regression

Table 41.-- *Matrix of simple correlation coefficients (r) among independent ($X_i$) variables for all stands. Values greater than ± .367 and .470 are significant at the 0.005 and 0.001 levels, respectively.*

| | Independent Variables | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | X(01) | X(02) | X(03) | X(04) | X(05) | X(06) | X(07) | X(08) | X(09) | X(10) | X(11) | X(12) | X(13) | X(14) | X(15) | X(16) | X(17) | X(18) | X(19) | X(20) | X(21) |
| Independent Variables | Live Stem BA/A | Dead Stem BA/A | Live Stem D/A | Dead Stem D/A | Live Stem Spac. | Dead Stem Spac. | Live Stem Vol/A | Dead Stem Vol/A | Live Stem Ht. | Dead Stem Ht. | Live Stem DBH | Dead Stem DBH | CCF | Site Index | Stand Age | Elevation | Terrain Slope | Live Stem $DBH^2$·Ht. | Live Stem DBH·Ht. | Dead Stem $DBH^2$·Ht. | Dead Stem DBH·Ht. |
| Live Stem BA/A, X(01) | 1 | .024 | .320 | -.089 | -.363 | -.384 | .579 | .019 | .015 | .262 | -.120 | -.008 | .521 | .324 | -.025 | -.007 | .046 | -.088 | -.071 | -.183 | -.068 |
| Dead Stem BA/A, X(02) | .024 | 1 | .185 | .482 | -.131 | -.589 | -.070 | .910 | -.130 | .456 | -.120 | .300 | .155 | -.456 | .634 | -.185 | .134 | -.083 | -.132 | .156 | .243 |
| Live Stem D/A, X(03) | .320 | .185 | 1 | .654 | -.877 | -.528 | -.450 | -.106 | -.806 | -.158 | -.864 | -.379 | .966 | -.289 | -.304 | -.349 | .032 | -.734 | -.803 | -.436 | -.448 |
| Dead Stem D/A, X(04) | -.089 | .482 | .654 | 1 | -.616 | -.444 | -.438 | .114 | -.573 | -.143 | -.648 | -.293 | .549 | -.386 | -.094 | -.360 | -.155 | -.518 | -.577 | -.304 | -.328 |
| Live Stem Spac., X(05) | -.363 | -.131 | -.877 | -.616 | 1 | .593 | .422 | .185 | .841 | .145 | .958 | .443 | -.906 | .292 | .432 | .392 | .050 | .899 | .913 | .572 | .542 |
| Dead Stem Spac., X(06) | -.384 | -.589 | -.528 | -.444 | .593 | 1 | .090 | -.442 | .470 | -.630 | .495 | -.348 | -.563 | .388 | -.184 | .244 | -.023 | .427 | .478 | -.099 | .213 |
| Live Stem Vol/A, X(07) | .579 | -.070 | -.450 | -.438 | .422 | .090 | 1 | .129 | .796 | .389 | .638 | .292 | -.307 | .588 | .317 | .325 | -.093 | .655 | .715 | .221 | .333 |
| Dead Stem Vol/A, X(08) | .019 | .910 | -.106 | .114 | .185 | -.442 | .129 | 1 | .147 | .604 | .211 | .518 | -.114 | .344 | .826 | -.041 | .175 | .213 | .171 | .385 | .487 |
| Live Stem Ht., X(09) | .015 | -.130 | -.806 | -.573 | .841 | .470 | .796 | .147 | 1 | .258 | .912 | .374 | -.756 | .555 | .375 | .410 | -.034 | .882 | .952 | .438 | .476 |
| Dead Stem Ht., X(10) | .262 | .456 | -.158 | -.143 | .145 | -.630 | .388 | .604 | .258 | 1 | .251 | .883 | -.102 | -.046 | .508 | .188 | .187 | .251 | .243 | .719 | .841 |
| Live Stem DBH, X(11) | -.120 | -.120 | -.864 | -.648 | .958 | .495 | .638 | .211 | .912 | .251 | 1 | .477 | -.848 | .359 | .502 | .404 | .017 | .958 | .975 | .558 | .569 |
| Dead Stem DBH, X(12) | -.008 | .230 | -.379 | -.293 | .443 | -.348 | .292 | .518 | .374 | .883 | .477 | 1 | -.369 | .007 | .498 | .329 | .133 | .464 | .428 | .938 | .977 |
| CCF, X(13) | .521 | .155 | .966 | .549 | -.906 | -.563 | -.307 | -.114 | -.756 | -.102 | -.848 | -.369 | 1 | .177 | -.338 | -.330 | .058 | -.744 | -.792 | -.467 | -.453 |
| Site Index, X(14) | .324 | -.456 | -.289 | -.386 | .292 | .388 | .588 | -.344 | .555 | -.046 | .359 | -.007 | -.177 | 1 | -.381 | .257 | -.050 | .353 | .423 | .054 | .033 |
| Stand Age, X(15) | -.025 | .634 | -.304 | -.094 | .432 | -.184 | .317 | .826 | .375 | .508 | .502 | .498 | -.338 | -.381 | 1 | .064 | -.024 | .546 | .489 | .436 | .532 |
| Elevation, X(16) | -.007 | -.185 | -.349 | -.360 | .392 | .244 | .325 | -.041 | .410 | .188 | .404 | .329 | -.330 | .257 | .064 | 1 | .240 | .413 | .419 | .397 | .365 |
| Terrain Slope, X(17) | .046 | .134 | .032 | -.155 | .050 | -.023 | -.093 | .175 | -.034 | .187 | -.017 | .133 | .058 | -.050 | -.024 | .240 | 1 | -.129 | -.082 | .135 | .146 |
| Live Stem $DBH^2$·Ht., X(18) | -.088 | -.083 | -.734 | -.518 | .899 | .427 | .655 | .213 | .882 | .251 | .958 | .464 | -.744 | .353 | .546 | .413 | -.129 | 1 | .980 | .559 | .560 |
| Live Stem DBH·Ht., X(19) | -.071 | -.132 | -.803 | -.577 | .913 | .478 | .715 | .171 | .952 | .243 | .975 | .428 | -.792 | .423 | .489 | .419 | -.082 | .980 | 1 | .515 | .533 |
| Dead Stem $DBH^2$·Ht., X(20) | -.183 | .156 | -.436 | -.304 | .572 | -.099 | .221 | .385 | .438 | .719 | .558 | .938 | -.467 | .054 | .436 | .397 | .135 | .559 | .515 | 1 | .973 |
| Dead Stem DBH·Ht., X(21) | -.068 | .243 | -.448 | -.328 | .542 | .213 | .333 | .487 | .476 | .841 | .569 | .977 | -.453 | .033 | .532 | .365 | .146 | .560 | .533 | .973 | 1 |

Table 42.-- *Matrix of simple correlation coefficients (r) among independent (X.) variables for all stands except LP-02 and LP-21. Values greater than ± .381 and .487 are significant at the 0.005 and 0.001 levels, respectively.*

| | Independent Variables | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Independent Variables | X(01) Live Stem BA/A | X(02) Dead Stem BA/A | X(03) Live Stem D/A | X(04) Dead Stem D/A | X(05) Live Stem Spac. | X(06) Dead Stem Spac. | X(07) Live Stem Vol./A | X(08) Dead Stem Vol./A | X(09) Live Stem Ht. | X(10) Dead Stem Ht. | X(11) Live Stem DBH | X(12) Dead Stem DBh | X(13) CCF | X(14) Site Index | X(15) Stand Age | X(16) Elevation | X(17) Terrain Slope | X(18) Live Stem $DBH^2 \cdot Ht$ | X(19) Live Stem $DBH \cdot Ht.$ | X(20) Dead Stem $DBH^2 \cdot Ht$ | X(21) Dead Stem $DBH \cdot Ht.$ |
| Live Stem BA/A, X(01) | 1 | -.074 | .264 | -.159 | -.310 | -.274 | .577 | -.060 | .059 | .157 | -.071 | -.100 | .476 | .330 | -.045 | .441 | -.030 | .964 | .977 | .597 | .626 |
| Dead Stem BA/A, X(02) | -.074 | 1 | .116 | .450 | -.060 | -.529 | -.106 | .904 | -.093 | .377 | -.073 | .233 | .072 | -.490 | .647 | .304 | .146 | .502 | .482 | .946 | .979 |
| Live Stem D/A, X(03) | .264 | .116 | 1 | .636 | -.871 | -.484 | -.495 | -.181 | -.805 | -.305 | -.862 | -.485 | .964 | -.308 | -.332 | .438 | -.037 | .885 | .952 | .466 | .520 |
| Dead Stem D/A, X(04) | -.159 | .450 | .636 | 1 | -.599 | -.411 | -.470 | .067 | -.562 | -.260 | -.636 | -.372 | .524 | -.401 | -.109 | .143 | .218 | .306 | .325 | .737 | .851 |
| Live Stem Spac., X(05) | -.310 | -.060 | -.871 | -.599 | 1 | .572 | .468 | .264 | .844 | .287 | .960 | .553 | -.901 | .310 | .464 | -.403 | .042 | -.745 | -.806 | -.492 | -.528 |
| Dead Stem Spac., X(06) | -.274 | -.529 | -.484 | -.411 | .572 | 1 | .182 | -.376 | .485 | -.518 | .496 | -.236 | -.508 | .499 | -.182 | -.401 | -.157 | -.518 | -.570 | -.342 | -.384 |
| Live Stem Vol./A, X(07) | .577 | -.106 | -.495 | -.470 | .468 | .182 | 1 | .108 | .822 | .384 | .671 | .277 | -.353 | .588 | .313 | -.054 | .064 | -.073 | -.038 | -.237 | -.137 |
| Dead Stem Vol./A, X(08) | -.060 | .904 | -.181 | .067 | .264 | -.376 | .108 | 1 | .189 | .568 | .266 | .482 | -.200 | -.364 | .838 | -.243 | .149 | -.069 | -.103 | .120 | .193 |
| Live Stem Ht., X(09) | .059 | -.093 | -.805 | -.562 | .844 | .485 | .822 | .189 | 1 | .354 | .912 | .434 | -.755 | .565 | .388 | .314 | -.086 | .667 | .736 | .211 | .322 |
| Dead Stem Ht., X(10) | .157 | .377 | -.305 | -.260 | .287 | -.518 | .384 | .568 | .354 | 1 | .363 | .879 | -.261 | -.066 | .534 | -.080 | .188 | .235 | .207 | .365 | .460 |
| Live Stem DBH, X(11) | -.071 | -.073 | -.862 | -.636 | .960 | .496 | .671 | .266 | .912 | .363 | 1 | .556 | -.864 | .371 | .521 | .450 | .032 | .915 | .921 | .634 | .627 |
| Dead Stem DBH, X(12) | -.010 | .233 | -.485 | -.372 | .553 | -.236 | .277 | .482 | .434 | .879 | .556 | 1 | -.490 | -.017 | .502 | .406 | -.041 | .486 | .511 | -.022 | -.119 |
| CCF, X(13) | .476 | .072 | .963 | .524 | -.901 | -.508 | -.353 | -.200 | -.755 | -.261 | -.846 | -.490 | 1 | -.195 | -.372 | .056 | -.024 | .552 | .501 | .432 | .531 |
| Site Index, X(14) | .330 | -.490 | -.308 | -.401 | .310 | .499 | .588 | -.364 | .565 | -.066 | .371 | -.017 | -.195 | 1 | -.384 | -.392 | .072 | -.760 | -.798 | -.535 | -.546 |
| Stand Age, X(15) | -.045 | .647 | -.332 | -.109 | .464 | -.182 | .313 | .838 | .388 | .534 | .521 | .502 | -.372 | -.384 | 1 | .256 | -.052 | .355 | .430 | .049 | .027 |
| Elevation, X(16) | -.054 | -.243 | -.403 | -.401 | .450 | .406 | .314 | -.080 | .438 | .143 | .441 | .304 | -.392 | .256 | .056 | 1 | .255 | .428 | .443 | .385 | .347 |
| Terrain Slope, X(17) | .064 | .149 | .042 | -.157 | .032 | -.041 | -.087 | .188 | -.037 | .218 | -.030 | .146 | .072 | -.051 | -.024 | .255 | 1 | -.141 | -.092 | .141 | .156 |
| Live Stem $DBH^2 \cdot Ht.$, X(18) | -.073 | -.069 | -.745 | -.158 | .915 | .486 | .667 | .235 | .885 | .306 | .964 | .502 | -.760 | .355 | .552 | .428 | -.141 | 1 | .982 | .574 | .586 |
| Live Stem $DBH \cdot Ht.$, X(19) | -.038 | -.103 | -.806 | -.570 | .921 | .511 | .736 | .207 | .952 | .325 | .977 | .482 | -.798 | .430 | .501 | .443 | -.092 | .982 | 1 | .540 | .572 |
| Dead Stem $DBH^2 \cdot Ht.$, X(20) | -.237 | .120 | -.492 | -.342 | .634 | -.022 | .211 | .365 | .466 | .737 | .597 | .946 | -.535 | .049 | .432 | .385 | .141 | .574 | .540 | 1 | .975 |
| Dead Stem $DBH \cdot Ht.$, X(21) | -.137 | .193 | -.528 | -.384 | .627 | -.119 | .322 | .460 | .520 | .851 | .626 | .979 | -.546 | .027 | .531 | .347 | .156 | .586 | .572 | .975 | 1 |

Table 43.-- *Summary of regression equations and pertinent statistics. All regressions are significant at the 99.5 percent level.*

| Equation | $R^2$ | F | $SE(\hat{Y})$ | $\bar{Y}$ | CV[1] |
|---|---|---|---|---|---|
| $\hat{Y}$ (<0.25" size class loading) = 0.07271 + 0.00019 (Dead Stem Density) + 0.00006 (Live Stem Volume) | 0.615 | 19.957 | 0.099 | 0.323 | 31 |
| $\hat{Y}$ (0.25-0.99" size class loading) = 0.02994 + 0.00059 (Dead Stem Density) + 0.00445 (Age) | .588 | 17.811 | 0.386 | 0.825 | 47 |
| $\hat{Y}$ (1.0-2.99" size class loading) = 0.55717 + 0.07835 (Dead Stem Basal Area) - 0.00032 (Dead Stem $DBH^2$·Height) | .480 | 10.623 | 0.947 | 1.376 | 69 |
| $\hat{Y}$ (3.0" + sound size class loading) = - 1.41225 + 0.00819 (Dead Stem Volume) + 0.25324 (Live Stem DBH) | .663 | 24.623 | 1.231 | 1.093 | 113 |
| $\hat{Y}$ (cone loading) = 0.07559 + 0.00035 (Live Stem Volume) + 0.00688 (Age) | .457 | 10.117 | 0.656 | 1.706 | 38 |
| $\hat{Y}$ (litter loading) = 0.32135 + 0.02310 $\sqrt{\text{Live Stem Volume}}$ | .309 | 11.621 | 0.393 | 1.433 | 27 |
| $\hat{Y}$ (duff loading) = -0.06390 + 0.37068 (Age) - 0.00105 $(Age)^2$ | .649 | 37.976 | 6.811 | 22.498 | 30 |
| $\hat{Y}$ (dead fuel depth) = 1.66503 + 0.00054 (Dead Stem Density) + 0.00032 (Live Stem Volume) | .407 | 8.582 | 0.486 | 2.710 | 18 |
| $\hat{Y}$ (live fuel depth) = - 0.17928 + 0.00806 (Live Stem DBH) | .455 | 21.745 | 1.321 | 1.285 | 103 |
| $\hat{Y}$ (duff depth) = -0.00405 + 0.02347 (Age) - 0.00007 $(Age)^2$ | .649 | 37.976 | 0.431 | 1.425 | 30 |
| $\hat{Y}$ (understory vegetation loading) = - 0.04896 + 0.00101 (Live Stem DBH·Height) | .420 | 18.823 | 0.178 | 0.134 | 133 |
| Version 1 | | | | | |
| $\hat{Y}$ (distance to live crown base) = - 3.03488 + 0.43851 (Live Stem Height) + 0.03831 (Live Stem Basal Area) | .668 | 28.135 | 3.831 | 16.432 | 23 |
| Version 2 | | | | | |
| $\hat{Y}$ (distance to live crown base) = 2.74312 + 0.44047 (Live Stem Height) | .638 | 45.768 | 4.077 | 16.432 | 25 |

[1]The coefficient of variation of the average predicted values, $\hat{Y}$'s, is estimated by $SE(\hat{Y})/\bar{Y} \times 100\%$.

($R^2$ 0.615). Stand age as a second variable in the latter size class proved to be the most significant (resulting $R^2$ of 9.588) of all possible independent variables. The signs of the coefficients in both regressions were positive.

Dead stem basal area and the 1.0-2.99 inch size class were positively correlated-- r of 0.634 which is the highest correlation for any one independent variable. The product of dead stem D.B.H. squared times height as a second variable improved the regression by 8 percent (from $R^2$ of 0.402 to 0.480). The sign of the regression coefficient for DBH x height was negative.

Not even a marginal useful regression could be developed for the 3.0 + inch rotten size class. Mean values and related statistics based on 45 sampled stands ranging in age between 1 to 370 years (Table 44) represent a combination of Clagg's (1975) work and the present study data stratified by stand age-classes based on presumed snag fall rates and decay considerations. The 3.0 + inch rotten size class was also stratified by aspect (Table 45).

Dead stem volume and live stem D.B.H. accounted for 66 percent of the total variation in the 3.0 + inch sound size class loading. Regression coefficients of the independent variables were both positive.

Live stem volume and stand age accounted for 46 percent of the total variation in the loading of seed cones on the forest floor. The equation presented in Table 43 for cone loading was the best overall when compared to all possible combinations tested. The sign of the regression coefficients were positive.

The best regression for estimating litter loading utilized the square root of live stem volume and accounted for only 31 percent of the

Table 44.-- *Loading of downed rotten material ≥ 3.0 inches in diameter by stand age-classes. Values are based on present study data and Clagg (1975).*

| Stand Age-Class (yrs.) | Statistics | | | | | Number of Stands |
|---|---|---|---|---|---|---|
| | $\bar{x}$ | Range | S | $S_{\bar{x}}$ | CV | |
| <40 | 0.590 | 0.0-1.643 | 0.681 | 0.257 | 115 | 7 |
| 40-100 | 10.528 | 0.042-23.879 | 9.114 | 2.631 | 87 | 12 |
| 100-160 | 5.045 | 0.0-23.805 | 6.313 | 1.448 | 125 | 19 |
| 160+ | 4.618 | 0.0-10.964 | 3.875 | 1.464 | 84 | 7 |

Table 45.-- *Loading of downed rotten material ≥ 3.0 inches in diameter by stand age-classes. Values are based on present study data and Clagg (1975).*

| Aspect[1] | Statistics | | | | | Number of Stands |
|---|---|---|---|---|---|---|
| | $\bar{x}$ | Range | S | $S_{\bar{x}}$ | CV | |
| North | 4.194 | 0.0-8.325 | 3.083 | 0.748 | 74 | 17 |
| East | 2.757 | 0.0-10.964 | 3.962 | 1.253 | 145 | 10 |
| South | 8.291 | 0.0-23.006 | 9.559 | 3.023 | 115 | 10 |
| West | 10.096 | 0.330-23.879 | 10.177 | 3.598 | 101 | 8 |

[1]North = 315° to 45°; East = 45° to 135°; South = 135° to 225°; West = 225° to 315°.

total variation (Fig. 13). Variation in litterfall sampled by Moir (1972) is illustrated in Figure 13. Note the extremes found by Moir in relation to the regression line and the present study data. Moir's data is not included in the regression because live stem volume could only be estimated from the data found in Moir and Grier (1969). The addition of other possible independent variables (e.g., stand age, elevation) did not improve the correlation.

Dead stem density and live stem volume were found to produce the best overall regression for dead fuel depth ($R^2$ of 0.407). Both regression coefficients were positive.

The product of live stem D.B.H. times height proved to explain the greatest degree of variation in live fuel depth ($R^2$ of 0.455). As illustrated in Figure 14, although stocking (indicated by DBH x Height) influences the obtainable height of understory vegetation so too does the characteristic understory flora. For this reason, representative live fuel depths were determined (Table 46).

Duff depth data from Clagg's (1975) seventeen stands and the present study were combined and plotted against stand age (Figure 14). A second degree polynominal indacted by the solid line in Figure 14 provided the best fit accounting for 65 percent of the total variation. The dashed line plotted in Figure 15 is a regression based on only those stands less than 200 years old. This was done in order to visualize the influence of those sampled stands between 200 and 300 years on the downward trend after approximately 175 years. In both cases, Clagg's 370-year-old stand was not included in the analysis because it was considered atypical at 10,300 feet in elevation on a south aspect. Note that there is a break in the x-axis after 300 years. Other stand

Figure 13.-- *Litter loading as a function of the square root of live stem volume. Regression accounted for 31 percent of the total variation. Moir's (1972) data is not included in the regression. Vertical line extending from Moir's data points represents the range in loading over three or more years.*

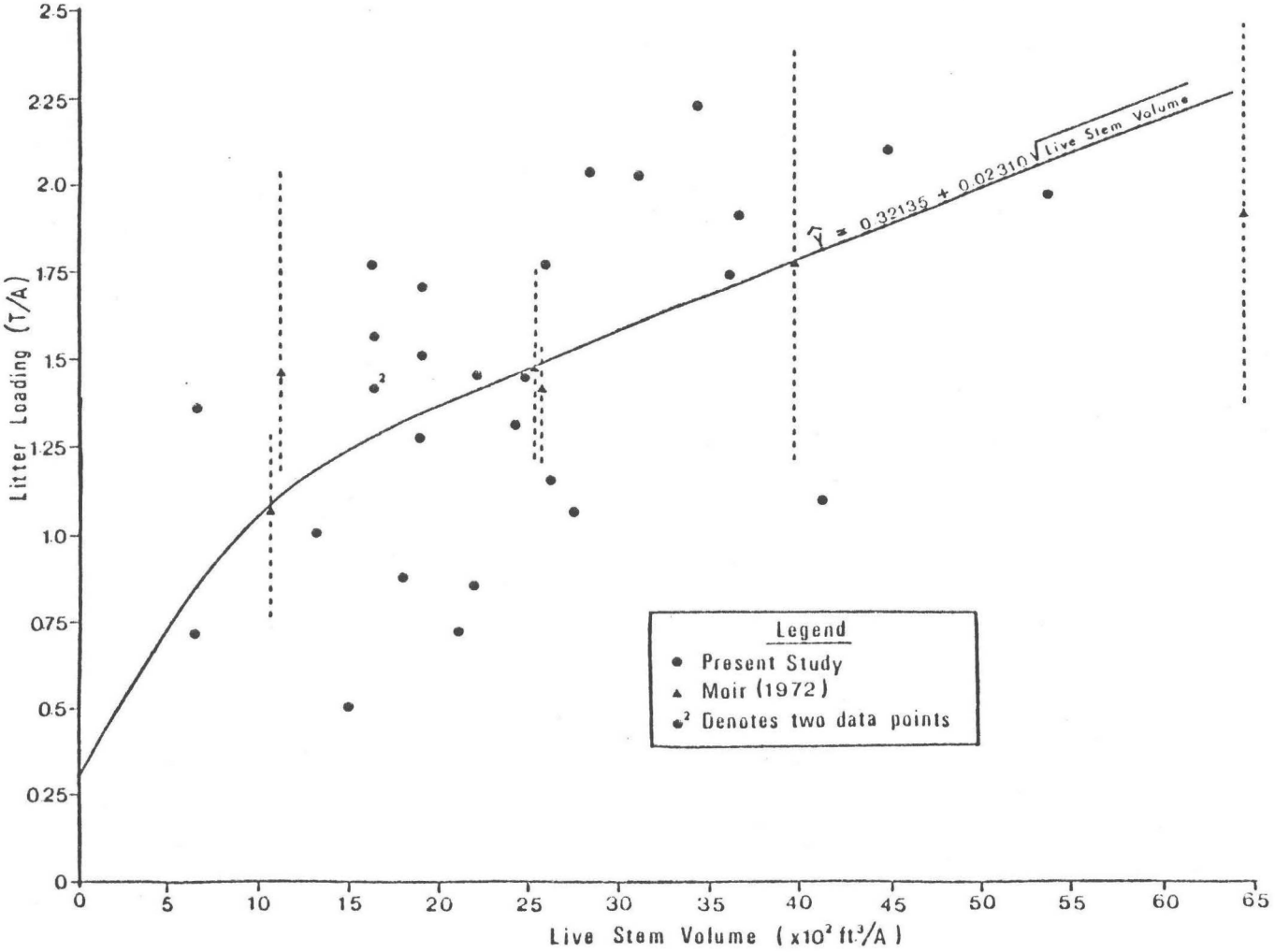


Figure 14.-- *Live fuel depth as a function of live stem diameter-at-breast-height (D.B.H.) times height. Regression accounted for 46 percent of the total variation. Refer to Table 13 for description of code names given in the legend.*

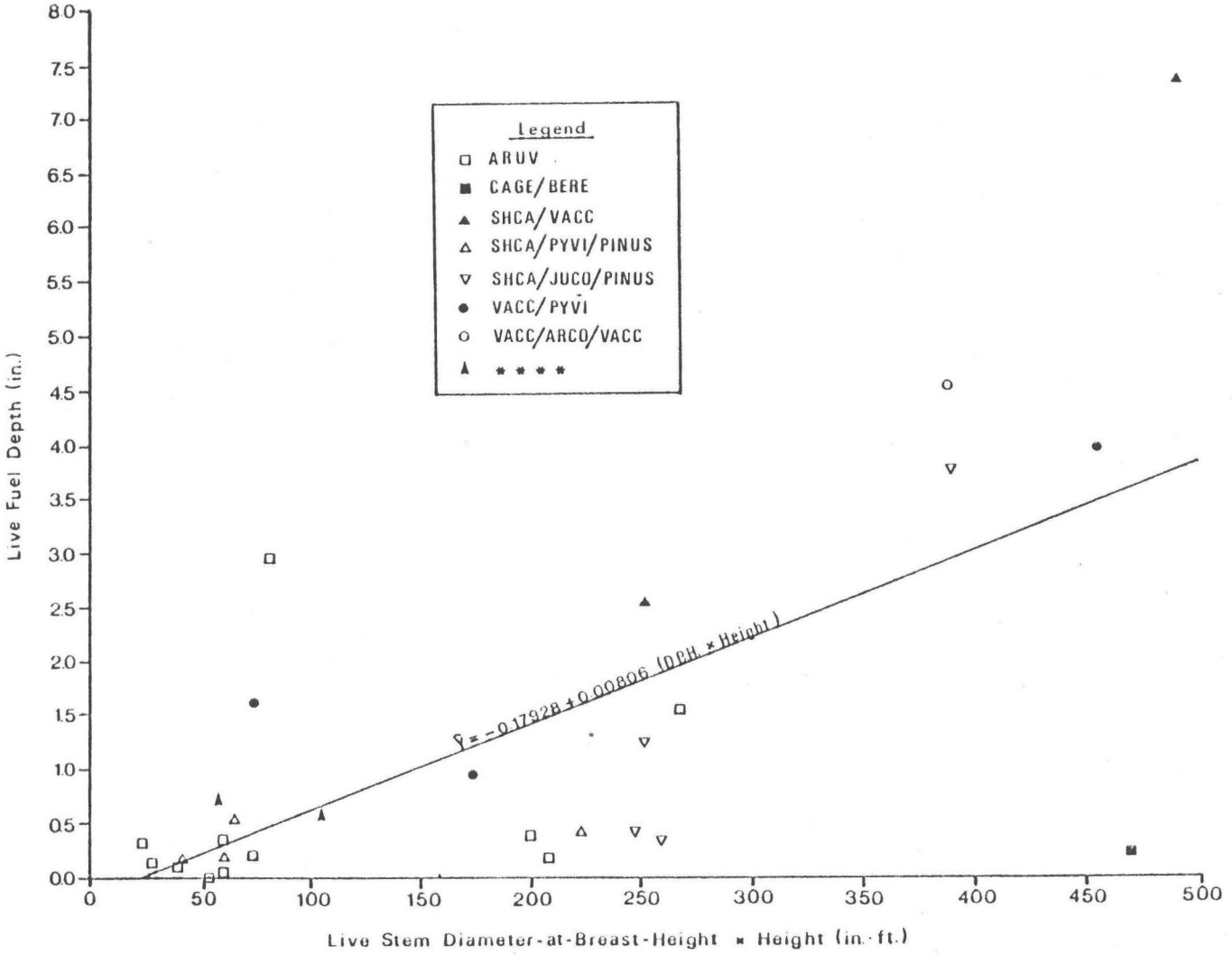
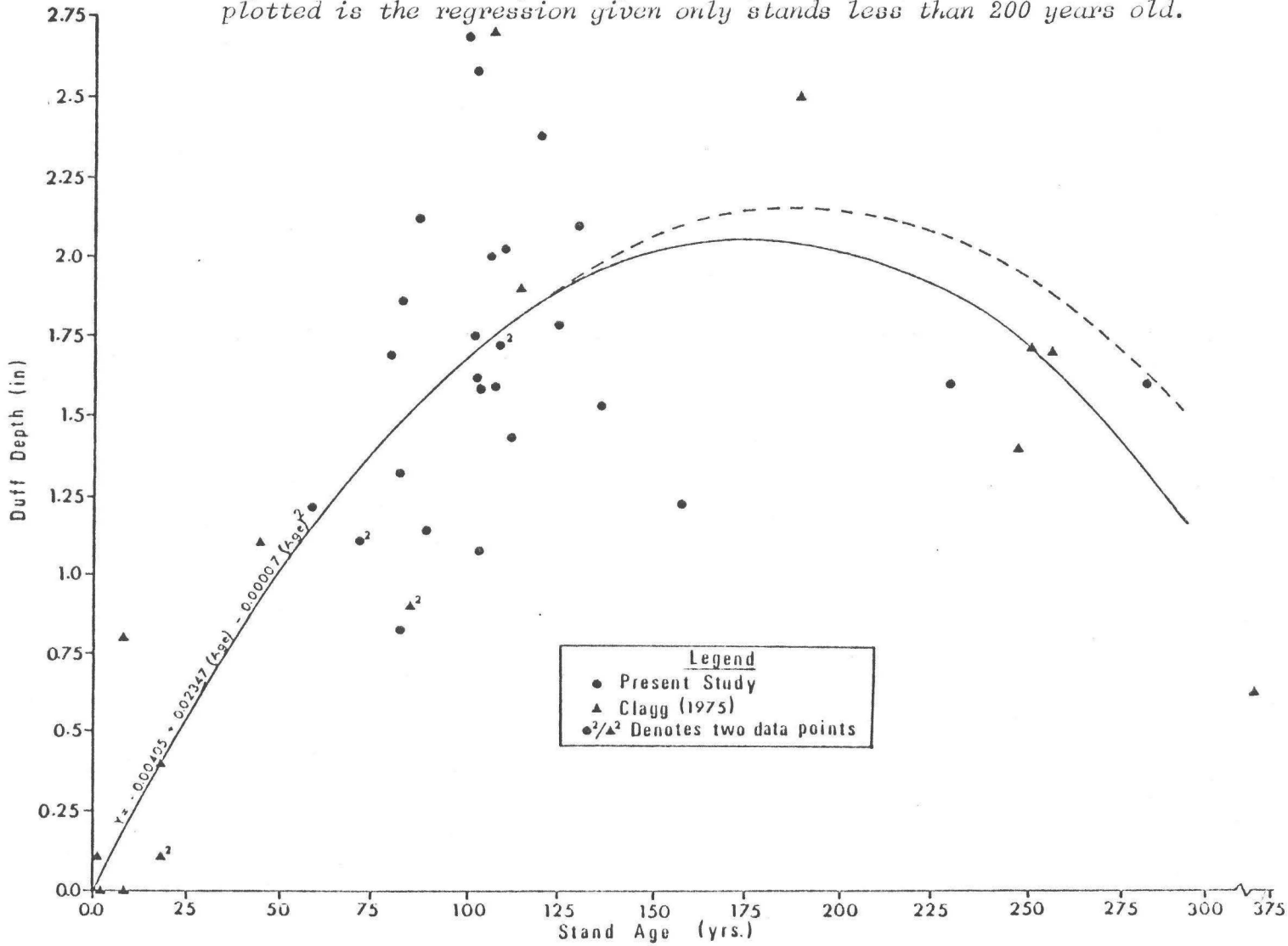


Table 46.-- *Representative live fuel depth by vegetation divisions and types/phases.*

| Code Name[1] | Statistics | | | | | Number of Stands |
|---|---|---|---|---|---|---|
| | $\bar{x}$ | Range | s | $s_{\bar{x}}$ | CV | |
| ARUV | 0.0514 | 0.0017-0.1960 | 0.0679 | 0.0205 | 132 | 11 |
| CAGE/BERE | 0.0176 | - | - | - | - | 1 |
| SHCA | 0.2031 | 0.0024-1.0502 | 0.3287 | 0.1039 | 162 | 10 |
| SHCA/VACC | 0.6150 | 0.1797-1.0502 | 0.6155 | 0.4353 | 100 | 2 |
| SHCA/PYVI/PINUS | 0.0339 | 0.0024-0.1050 | 0.0482 | 0.0241 | 142 | 4 |
| SHCA/JUCO/PINUS | 0.1664 | 0.0158-0.4591 | 0.2061 | 0.1030 | 124 | 4 |
| VACC | 0.2807 | 0.1075-0.5820 | 0.2221 | 0.1110 | 79 | 4 |
| VACC/PYVI | 0.1803 | 0.1075-0.3140 | 0.1160 | 0.0670 | 64 | 3 |
| VACC/ARCO/VACC | 0.5820 | - | - | - | - | 1 |
| **** | 0.0134 | 0.0124-0.0144 | 0.0014 | 0.0010 | 10 | 2 |

[1]Refer to Table 13 for description of code names.

Figure 15.-- *Duff depth as a function of stand age. Clagg's (1975) data is included in the regression with one exception. The data point at 370 years is not included. Regression accounted for 65 percent of the total variation. The dashed line plotted is the regression given only stands less than 200 years old.*



structure and site variables or combinations thereof could not account for the degree of variation explained by the two degree polynominal using stand age. The same analysis described above was utilized in developing a regression for duff loading.

Clagg (1975) had previously found greater duff depths on northerly aspects when compared with more southerly exposures. Duff depths from Clagg (1975) and the present study were ordinated against slope exposure (Fig. 16). No discernible trend in duff depth versus slope aspect could be ascertained. For this reason, separate equations were not justified.

The best equation developed for understory vegetation (live and dead) used the product of live stem D.B.H. times height. The regression accounted for 42 percent of the total variation (Fig. 17). Representative understory vegetation loadings were determined for the same reason given in live fuel depth (Table 47).

Distance to live crown base (DLCB) was reasonably well correlated ($R^2$ 0.638) with mean live stem height as would be expected. A least square regression was then calculated (Fig. 18) in order to approximate DLCB from aerial photographs given measurements of stand height. As one might expect, stocking has an influence on DLCB. Stand density and average spacing between stems were too highly correlated with height to be used. The addition of basal area as a measure of stocking improved the regression somewhat ($R^2$ 0.667). It should be stated that live stem volume is the single most highly correlated (r 0.821) independent variable with DLCB (Table 40). Volume is basically basal area times height with a stem form factor added. The height and basal area equation is designed for estimating DLCB from stand inventories.

Figure 16.-- *Duff depth as a function of slope aspect. Data from the present study and Clagg (1975). Stand age is noted adjacent to the depth point.*

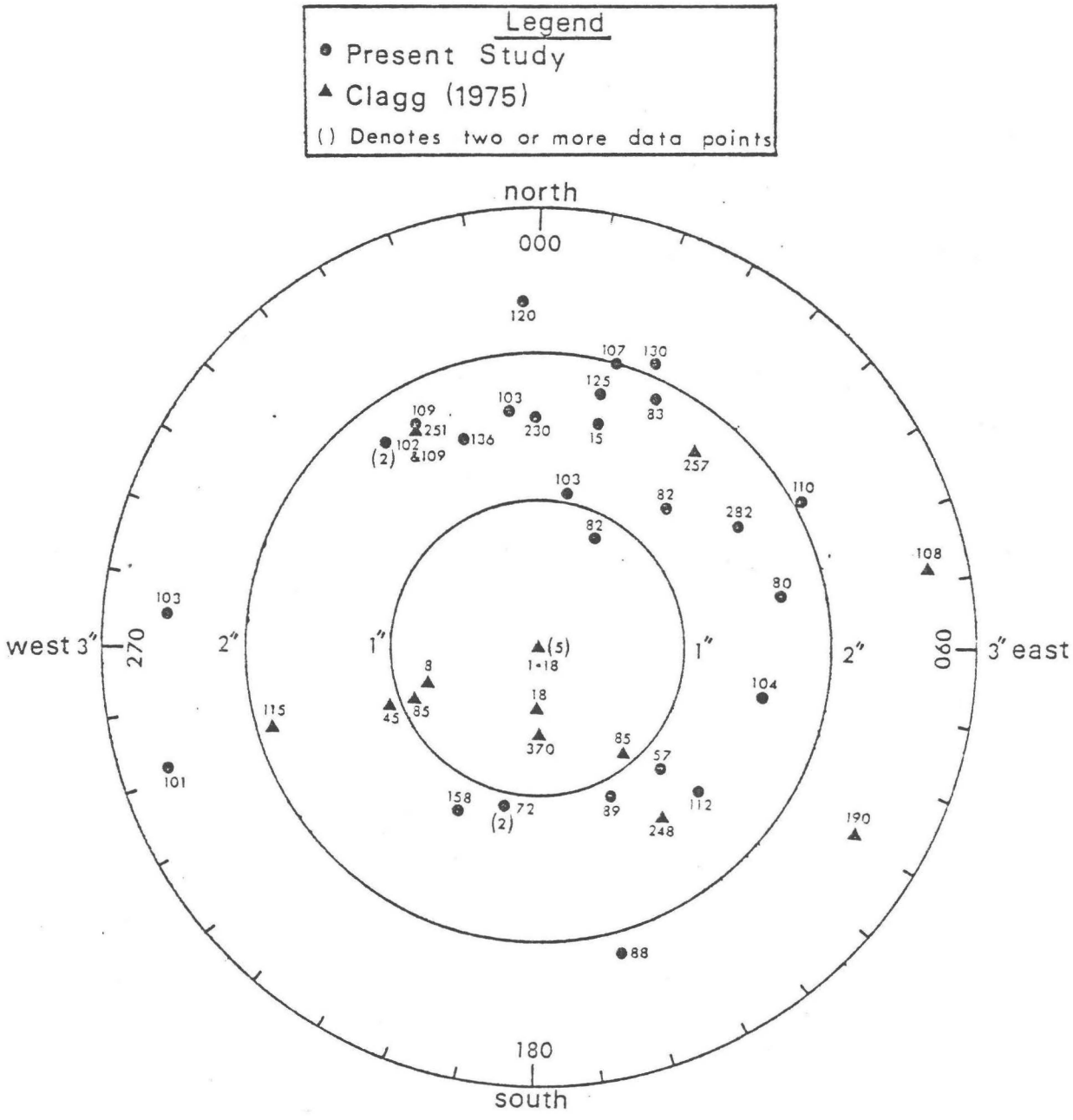


Figure 17.-- *Understory vegetation loading as a function of live stem diameter-at-breast-height (D.B.H.) times height. Regression accounted for 42 percent of the total variation. Refer to Table 13 for description of code names given in the legend.*

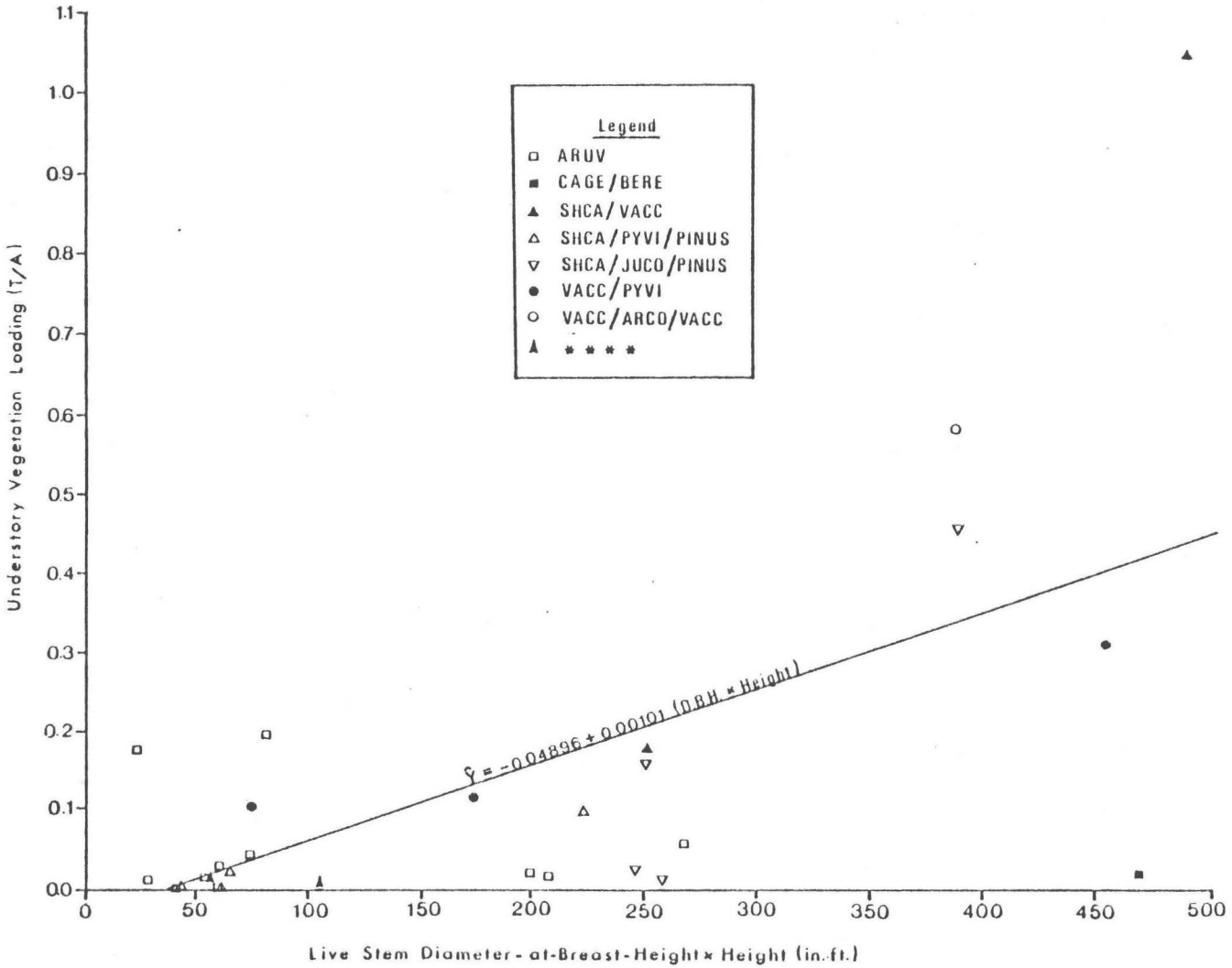
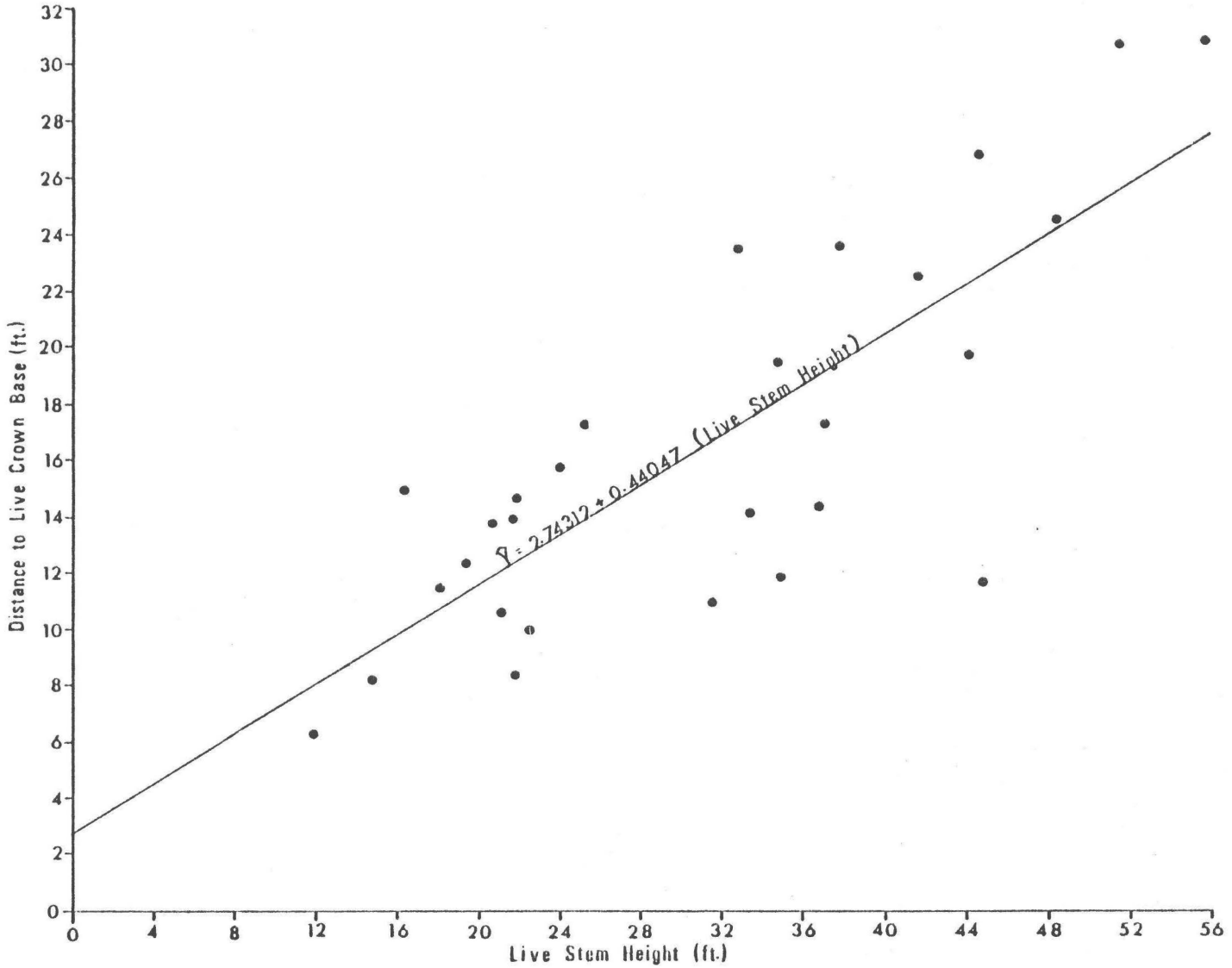


Table 47.-- *Representative understory vegetation loading by vegetation divisions and types/phases.*

| Code Name[1] | Statistics | | | | | Number of Stands |
|---|---|---|---|---|---|---|
| | $\bar{x}$ | Range | s | $s_x$ | CV | |
| ARUV | 0.57 | 0.0 - 2.94 | 0.88 | 0.27 | 154 | 11 |
| CAGE/BERE | 0.22 | - | - | - | - | 1 |
| SHCA | 1.71 | 0.19 - 7.35 | 2.31 | 0.73 | 135 | 10 |
| SHCA/VACC | 4.96 | 2.57 - 7.35 | 3.38 | 2.39 | 68 | 2 |
| SHCA/PYVI/PINUS | 0.35 | 0.19 - 0.55 | 0.17 | 0.09 | 49 | 4 |
| SHCA/JUCO/PINUS | 1.44 | 0.33 - 3.77 | 1.61 | 0.80 | 112 | 4 |
| VACC | 2.78 | 0.97 - 4.54 | 1.74 | 0.87 | 63 | 4 |
| VACC/PYVI | 2.19 | 0.97 - 3.96 | 1.57 | 0.91 | 72 | 3 |
| VACC/ARCO/VACC | 4.54 | - | - | - | - | 1 |
| **** | 0.66 | 0.59 - 0.72 | 0.09 | 0.07 | 14 | 2 |

[1]Refer to Table 13 for description of code names.

Figure 18.-- *Distance to live crown base as a function of live stem volume. Regression accounted for 64 percent of the total variation.*



Evaluation

Not all regressions could be tested due to certain missing independent variable data in the literature. Clagg's (1975) study data provided sufficient information to test the regression for the 0.25-0.99 inch size class loading. The loading values used are found in Table 22 of this thesis. Clagg used two methods of determining dead stem density, therefore, the mean density of the two methods was used. Nine acceptable stands ranging in age from 45 to 257 years and 5 to 380 dead stems per acre were tested. The regression had a standard error of the estimate of 47 percent of the mean value. Predicted weights for three stands varied from 23.2 to 54.1 ($\bar{x}$ 38.0) percent more than measured. Whereas, the remaining six stands varied from 13.1 to 61.9 ($\bar{x}$ 40.6) percent less.

Data adapted from Moir (1972) were utilized in testing the litter loading regression. The loadings values used were the stand means found in the right-hand columns of Table 2 of this thesis. Live stem volumes for six stands ranged from approximately 1,000 to 6,500 $ft^3$/A. These figures are slightly high because only dominant tree height was available for the volume computation. The regression had a standard error of the estimate of 27 percent of the mean value. Predicted weights for five stands varied from zero to 13.6 ($\bar{x}$ 4.0) percent more than measured, while the remaining stand was 25.3 percent less.

Moir and Grier's (1969) data provided an opportunity to evaluate the duff loading regression. Unfortunately, Moir and Grier did not measure duff depth. Duff depth would have been preferred because duff loading in the present study was estimated from depth and bulk density. The regression had a standard error of the estimate of 30 percent of the

mean value. Predicted weights from eight stands ranging in age from 67 to 99 years varied from 66.5 to 201.7 ($\bar{x}$ 118.5) more.

The only local data available to evaluate distance to live crown base (DLCB) comes from one stand on the Medicine Bow National Forest in southeastern Wyoming (Gary 1976). Measured stand height was 35.5 feet. The regression had a standard error of the estimate of 23 percent of the mean value. Predicted DLCB was 22 percent greater than measured.

## Live Crown Lenght Regression

An examination of simple correlation coefficients among live crown length and live stand structure characteristics revealed several satisfactory sets (Table 48). Any one set accounted for 69 to 84 percent of the total variation. A scatter diagram of live crown length versus D.B.H. revealed a curvilinear trend. A second degree polynominal using D.B.H. fit the data better than the variable sets noted above, accounting for 87 percent of the total variation (Fig. 19). The resulting equation and pertinent statistics are as follows:

$$\hat{Y} = -4.494041 + 5.46079 \text{ X } (1) - 0.25054 \text{ X } (1)^2$$

where, $\hat{Y}$ = live crown length, feet

X(1) = live stem D.B.H., inches

$R^2 = 0.873$ F = 85.691 SE($\bar{Y}$) = 2.742 $\bar{Y}$ = 14.471 CV = 19%

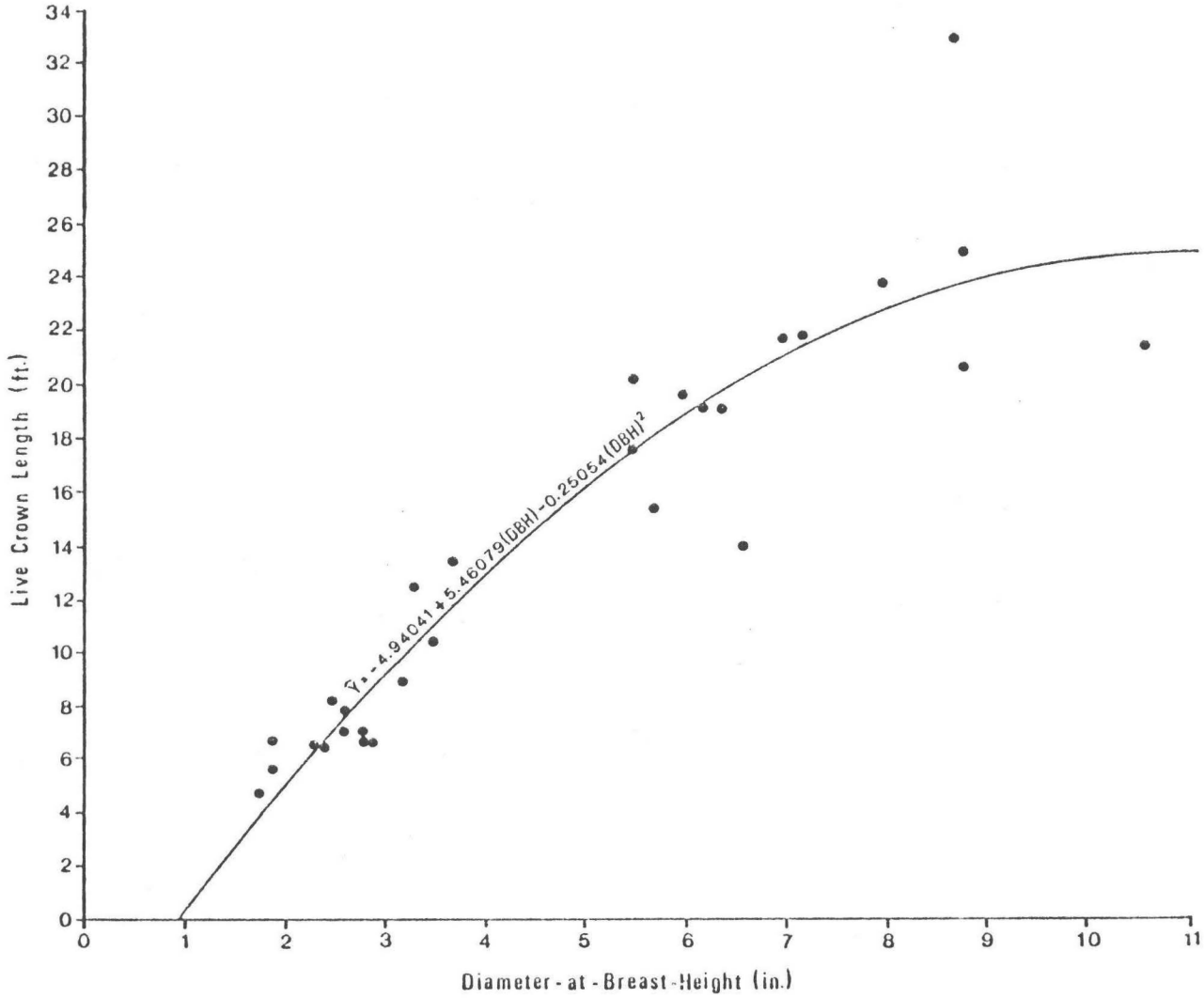
The regression was significant at the 99.5 percent level. Full statistics are given in Appendix E.

Gary's (1976) one stand from southeastern Wyoming utilized in evaluating the distance to live crown base equation was again used for the LCL regression. Mean stand D.B.H. was 5.2 inches. The LCL

Table 48.-- *Simple correlation coefficients (r) between live crown length and selected live stem characteristics.*

| Independent Variable Set | Simple Correlation Coefficient (r) |
|---|---|
| DBH | 0.914 |
| Height | .858 |
| DBH x Height | .882 |
| $DBH^2$ x Height | .829 |
| DBH + Basal Area | .919 |
| Height + Basal Area | .884 |
| DBH x Height + Basal Area | .893 |
| $DBH^2$ x Height + Basal Area | .839 |

Figure 19.-- *Live crown length as a function of live stem diameter-at-breast-height (D.B.H.). Regression accounted for 87 percent of the total variation.*



regression had a standard error of the estimate of 19 percent of the mean value. Predicted LCL was 18 percent less than measured.

## Shrub Weight Regressions

Twelve kinnikinnick (LP-01, 03, 04, 10, 13, 14, 19, 21, 25, 26, 27, and 28) and five *Vaccinium* spp. (LP-05, 07, 08, 16, 23 and 24) dominated stands provided for a variety of stand and site conditions. The average height of kinnikinnick seldom exceeded two inches so shrub height was disregarded as an independent variable. A least squares regression using percent cover accounted for 73% of the total variation in the data. A second degree polynominal yielded a better fit with an $R^2$ of 0.821. The resulting equation and pertinent statistics are contained in Table 49.

Independent variable sets with their respective simple correlation coefficient versus *Vaccinium* spp. weights that proved satisfactory was summarized in Table 50. The best regression selected used the product of cover times height; it accounted for 61 percent of the total variation in the data (Table 49).

The equations presented in Table 49 exhibited F ratios significant at the 99.5 percent level. Full statistics for both regressions are documented in Appendix E.

## Dwarf Mistletoe Comparisons

Stands LP-23 to LP-28 represent the three pairs of little or no infection versus heavily infected dwarf mistletoe stand comparisons of the same origin (LP-23 versus LP-24, etc.). The results of the comparisons including the level of dwarf mistletoe incidence presented in Table 51.

Table 49.-- *Equations for estimating shrub weights ($\hat{Y}$) of kinnikinnick and whortleberry in tons per acre, from cover ($X_1$), percent, and height ($X_2$), inches. Both equations exhibited F ratios significant at the 99.5 percent level.*

| Shrub Species | Equation | $R^2$ | F | SE | $\bar{Y}$ | CV | n |
|---|---|---|---|---|---|---|---|
| Kinnikinnick | $\hat{Y} = -0.000134 + 0.002194 X_1 + 0.000137 X_1^2$ | 0.821 | 268.104 | 0.085 | 0.109 | 78 | 106 |
| Whortleberry | $\hat{Y} = -0.06077 + 0.00180 X_1 X_2$ | .611 | 106.803 | 0.253 | 0.508 | 50 | 60 |

Table 50.-- *Simple correlation coefficients (r) between whortleberry fuel weight and selected independent variable sets.*

| Independent Variable Set | Simple Correlation Coefficient (r) |
|---|---|
| Cover | 0.506 |
| Cover Squared | .473 |
| Height | .710 |
| Height squared | .736 |
| Cover x Height | .782 |
| Cover x Height squared | .786 |
| Cover squared x Height | .707 |

Table 51.-- *Means and results of "t" tests on selected fuel descriptors of dwarf mistletoe stand comparisons.*

| Stand Comparison | Fuel Descriptors: Loading by Downed Woody Surface Fuels, T/A <0.25" | 0.25-0.99" | 1.0-2.99" | Dead Fuel Depth, in. | DLCB, ft. | Dwarf Mistletoe Incidence: $\bar{x}$ 6-Class Rating | Percent Infested |
|---|---|---|---|---|---|---|---|
| LP-23 | 0.183 | 0.141 | 0.404 | 1.75 | 11.0 | 0.1 | 5.5 |
| vs. | | | | | | | |
| LP-24 | 0.153 | 0.139 | 1.603 | 1.88 | 10.0 | 1.9 | 89.6 |
| *t* statistic | 0.463 | 0.013 | 1.409 | 0.394 | 1.836 | | |
| significance level | N.S.[1] | N.S. | 0.200 | N.S. | 0.070 (n=253)[2] | | |
| LP-25[3] | 0.582 | 1.181 | 3.998 | 1.91 | 15.8 | 4.0[3] | 98.2[3] |
| vs. | | | | | | | |
| LP-26 | 0.657 | 2.322 | 1.196 | 2.32 | 8.2 | 4.8 | 99.2 |
| *t* statistic | 0.614 | 1.899 | 2.189 | 0.101 | 30.297 | | |
| significance level | N.S. | 0.100 | 0.070 | N.S. | 0.001 (n=742) | | |
| LP-27 | 0.283 | 0.278 | 0.200 | 1.31 | 10.6 | <0.05 | 2.0 |
| vs. | | | | | | | |
| LP-28 | 0.413 | 1.524 | 0.598 | 2.67 | 6.3 | 5.6 | 99.6 |
| *t* statistic | 1.905 | 3.957 | 1.262 | 2.201 | 16.974 | | |
| significance level | 0.100 | 0.005 | 0.300 | 0.070 | 0.001 (n=652) | | |

[1]Not significant at even the 0.500 level.

[2]n = 8 unless otherwise noted.

[3]From field observations it was obvious that this stand was infested more recently than its comparison-- perhaps in the last 30 years whereas its comparison was probably infested immediately after the last fire. Dwarf mistletoe infested fire scarred residuals were immediately adjacent to stand LP-26.

The loading of < 0.25 inch size class fuels was greater in the heavily infested stands in two out of three cases but only significantly greater in one case. The 0.25-0.99 inch size class fuels were nearly equal in one stand comparison and significantly greater in the heavily infested stands of the other two comparisons. In two cases the weight of the 1.0-2.99 inch size class fuels was greater but not significantly in the heavily infested stands. In the remaining case, 1.0-2.99 inch size class fuels were significantly greater in the less infected stand. Dead fuel depth was higher in the heavily infested stands of all three comparisons but only significant in one case.

In all three comparisons, distance to live crown base (DLCB) was significantly lower in the heavily infested stands. Live stem density and crown bulk density were nearly equal in one comparison and greater in the heavily infested stands of the remaining two cases.

# CHAPTER 5 - DISCUSSION AND CONCLUSIONS

The purpose of this chapter is to provide an explanation of results obtained, note comparisons with other studies, and summarize progress made relative to the primary and associated study objectives. Finally, applications of study results are briefly described and recommendations are made for future research. Statements and conclusions are supported by observations and data.

## Fuel Measurement and Inventory

All basic data such as number of size class intersections, 3.0 + inch size class diameters, and depths by plot for each of the 28 sampled stands have been adequately documented (Alexander et al. 1976) for reference and use by future investigators. Mean stand fuel characteristics have been archived in the Natural Forest Fuels Data Bank. Sample data obtained represent the most complete fuels description to date of a wide variety of even-aged lodgepole pine stands in Colorado and the Southern Rocky Mountains.

Downed woody fuel and forest floor loadings and depths are within the range reported by previous investigators in western North American lodgepole pine forests. The major difference between Clagg's (1975) previous work in northcentral Colorado and the present study is in the quantity of downed woody sound fuels three inches and greater in diameter. Fuel loadings determined by Clagg were approximately ten times greater on the average when study means are compared. The reason for this difference is presumably due to elevation.

Understory vegetation weights and live fuel depths obtained are typically at the lower end of the scale compared to previous studies in more northern lodgepole pine forests. Seasonal and annual variation in understory vegetation growth could be partially responsible, but poor site conditions are more likely the major factor.

The natural fuel photo series resulting from the present study efforts (Alexander 1978) represents the first attempt to provide a pictorial array of fuel and stand conditions for lodgepole pine forests in Colorado and the Southern Rocky Mountains. The present series composed of 28 stands should be supplemented by additional sampling in different stand conditions.

Percent errors obtained in fuel sampling were, on the average, in fair agreement with recommendations on sampling intensity suggested by Brown (1974c) based on past experience in the Northern Rocky Mountains. Oberheu and Mutch (1975) reported percent errors as low as seven percent for many highly homogeneous lodgepole pine stands in the Central Rocky Mountains. Prior to the present study, percent errors in fuel sampling have never been reported in Southern Rocky Mountain lodgepole pine stands. Suggestions on sampling intensity for cones, understory vegetation, and live fuel depth were unavailable. Percent errors experienced in the present study should assist future investigators, in Colorado, in deciding the optimum number of plots and length of line per fuel size class, especially for the 1.0-2.99 and 3.0 + inch size classes.

Crown fuel component calculations using weight tables (Brown et al. 1977) rather than computer assisted computations illustrated the sensitivity of loading values to the percentage of intermediate and suppressed stems. Timber stand inventories should note the crown class of each tally stem.

## Fuel Complex Characterization

Findings from the $t$ test analyses indicate that for some fuel characteristics, significant differences exist between the stylized sapling and pole/sawtimber stand categories. However, characterization of all fuel characteristics according to stylized stand habit is not universal. In these instances, the "all stand" mean would be more representative. Significant differences are more consistent in the aerial than the ground and surface fuel complex stratas.

Fuel inventory data obtained in the present study have permitted the most complete breakdown of the lodgepole pine forest fuel complex, encompassing individual stratas and components. For instance, Clagg (1975) concluded, presumably without considering all the components, that the total 3.0 + inch size class comprised 99 percent by weight of the surface fuel strata. Findings from the present study, based on 28 stands, indicate that 50 percent is a more representative figure.

The value of characterizing fuels according to similar biological potential afforded by Steen and Dix's (in prep.) phytosociological classification was particularly evident in understory vegetation weights and live fuel depths as pointed out in the fuel prediction section of Chapter 4. Data presented in tables 37 and 38 are for the most part too few to reliably characterize fuels at the present time. A start has been made but additional sampling is needed.

## Fuel Prediction Models

The scatter diagrams of loading plotted against age illustrate that correlating woody fuel quantities with only stand life chronology is not necessarily the best approach to fuel prediction. The affinity of

downed woody surface fuels to be more closely correlated with dead stem characteristics rather than live stem attributes, as borne out by the simple correlation coefficients, is in agreement with Muraro (1971). Live stem characteristics were on the other hand more closely related to living fuel descriptors such as understory vegetation and distance to live crown base.

The independent variables and coefficient signs for all regressions are summarized in Table 52. The fact that dead stem density appeared in the final equations for the < 0.25 and 0.25-0.99 inch size classes illustrates that the primary source of downed debris in these size classes is material contained in the "crowns" of dead stems. After a stem dies, it slowly deteriorates, eventually depositing its "fines" to the surface fuel strata. The inclusion of live stem volume in the < 0.25 inch size class regression, and stand age in the 0.25-0.99 inch size class regression, is believed to be a reflection of the contribution made by the living component of the stand.

Dead stem basal area rather than density, coupled with the average height and size (D.B.H.) were responsible for explaining the greatest degree of variation in the 1.0-2.99 inch size class loading. The negative coefficient sign of D.B.H. x height indicates that the presence of large dead stems in the stand lessens the chance of encountering downed 1.0-2.99 inch size class fuels. As pointed out in Chapter 2, debris quantities within the 1.0-2.99 inch size class range, at least in lodgepole pine stands, are principally a function of suppression mortality rather than twig and branch shedding. Some stands experience heavy suppression mortality and others do not. Differences in stand history are believed to hinder improvement of the regression.

Table 52.-- *Independent variable(s) present in final regression equations for dependent variable estimation.*

| Independent Variables | Dependent Variables | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | <0.25" size class loading | 0.25-0.99" size class loading | 1.0-2.99" size class loading | 3.0"+ sound size class loading | cone loading | litter loading | duff loading | dead fuel depth | live fuel depth | duff depth | understory vegetation loading | distance to live crown base |
| Live Stem BA/A | | | | | | | | | | | | X(+)[1] |
| Dead Stem BA/A | | | X(+) | | | | | | | | | |
| Live Stem D/A | | | | | | | | | | | | |
| Dead Stem D/A | X(+) | X(+) | | | | | | X(+) | | | | |
| Live Stem Spac. | | | | | | | | | | | | |
| Dead Stem Spac. | | | | | | | | | | | | |
| Live Stem Vol./A | X(+) | | | | X(+) | X(+) | | X(+) | | | | |
| Dead Stem Vol./A | | | | X(+) | | | | | | | | |
| Live Stem Ht. | | | | | | | | | | | | X(+)[1,2] |
| Dead Stem Ht. | | | | | | | | | | | | |
| Live Stem DBH | | | | X(+) | | | | | | | | |
| Dead Stem DBH | | | | | | | | | | | | |
| CCF | | | | | | | | | | | | |
| Site Index | | | | | | | | | | | | |
| Stand Age | X(+) | | | | | | X(±) | | | X(±) | | |
| Elevation | | | | | X(+) | | | | | | | |
| Terrain Slope | | | | | | | | | | | | |
| Live Stem $DBH^2 \cdot Ht.$ | | | | | | | | | | | | |
| Live Stem $DBH \cdot Ht.$ | | | | | | | | | X(+) | | X(+) | |
| Dead Stem $DBH^2 \cdot Ht.$ | | | X(-) | | | | | | | | | |
| Dead Stem $DBH \cdot Ht.$ | | | | | | | | | | | | |

[1]Used in version 1.

[2]Used in version 2.

The volume of standing dead stems is a good and logical indicator of the abundance of 3.0 + inch sound size class material that has fallen or eventually will fall to the ground surface. Inclusion of live stem D.B.H. indicates that stands with large stem diameters are more likely to have greater quantities of 3.0 + inch size class fuels.

Live stem volume is believed to be as good an index of total cones as possible. Inclusion of stand age is perceived to be a reflection of the decay resistance of fallen seed cones and stand maturity. Improvement in the regression was hindered by data variation due to squirrel activities in certain stands.

Live stem volume also appears as the best index for estimating litter loading. The reason for this relationship is linked to the fact that stem and crown volume are mutally related. In turn, needle amount is largely dependent upon crown volume which determines potential needle fall. The resulting $R^2$ of 0.31 is lower than that 0.45 using basal area as obtained by Kiil (1967b, 1968). However, it must be remembered that Kiil sampled only 70 year-old stands of three different densities on one site. Considering the inherent seasonal and yearly variation of litter fall found by Moir (1972), coupled with additional variation from squirrel activity, the regression appears quite satisfactory for estimation purposes.

Dead fuel depth measurements consisted principally of litter and woody debris particles less than one inch in diameter. The fact that litter loading correlated best with live stem volume, and the two fuel size classes < 1.0 inch in diameter were intimately associated with dead stem density, would explain the reason for this relationship.

The interpretation of stand age versus duff depth and loading is as follows. The stand establishing fire generally removes the entire duff layers during flame front passage and subsequent persistence. Post-fire woody fuels, which contribute to the creation of the duff layer, fall and begin to decay. Post-fire vegetation provides annual increments of dead organic material. The duff mantle slowly formulates as the stand develops. Litter fall increases. Maximum crown closure and litter fall is reached. The stand then begins to open up and litter fall is relatively constant. At this point it is believed that decomposition begins to equal and possibly exceed production. Whether the duff mantle decreases after approximately 175 years is difficult to say because of few sampled stands beyond this age. Disregarding site conditions, data variation is associated principally with stand history.

Live fuel depth and understory vegetation loading were found to be reasonably related to stem stocking represented by live stem DBH x height. $R^2$ values were 0.46 and 0.42, respectively. However, the characteristic understory species exerted a significant influence. For this reason, the representative values found in tables 46 and 47 are suggested for interim use. Additional data is needed to ultimately develop a family of phytosociological curves for height and weight at different stocking levels. One would expect greater quantities and heights in more open stands. Kiil (1967b, 1968) found live stem basal area to be the best measure of stocking in estimating understory vegetation weights ($R^2$ of 0.49).

The fact that distance to live crown base (DLCB) correlated best with live stem height comes as no surprise. Muraro (1971) found height to be better related than DBH. Obviously stem stocking has an influence. Live stem basal area as a measure of stocking was the only independent

variable that could be used. The estimation of DLCB on a stand basis has certain advantages over determination on an individual tree basis (e.g., quickness of estimation). Improvement in the present regression is both desirable and possible.

Downed rotten material three inches and greater in diameter is extremely difficult to model. Rotten debris is primarily a function of the antecedent fire-killed stand and, to a much lesser degree, sound material from natural mortality that begins accelerated decay once the dead stem is in contact with the ground surface. This is borne out by viewing loading versus age-classes presented in Table 44. The processes involved are extremely complex, incorporating different decay rates due to temperature and moisture regimes, fire frequency, and tree size abundance prior to the stand establishing fire. Although considerable variation exists, mean loadings stratified by aspect indicate that north/east aspects typically have lower quantities of rotten material compared to south/west facing exposures. Cooler microclimatic conditions on north and east facing exposures, thus less decay activity converting sound debris to rotten material, is suspected as being responsible for this trend. Additional sampling and analysis is needed to relate 3.0 + inch rotten size class to stand history and various environmental factors, principally aspect and elevation. The data contributed by Clagg (1975) and the present study data, consisting of 45 stands, provides an excellent foundation for further work to resolve this matter to a reasonable degree.

Considering the inherent difficulties in natural fuel prediction as amply described in Chapter 2, the resulting regressions were surprisingly good. In each regression, one or two stand characteristics explained a substantial portion of the total variation in the data. The regression

equations developed should not be conceived directly as cause and effect relationships but merely as products of the data fitting process. However, the final independent variables selected and the coefficient signs appear to have a logical relationship to the dependent variables.

Kiil (1967b, 1968) and Muraro (1971) had essentially the same objectives as primary objective 1 of the present study. Both Kiil and Muraro met with varying degrees of success. Kiil concluded that poor correlations between stand characteristics and downed woody debris were due to fuel variability and sampling problems. In addition, Kiil sampled a limited range of stand conditions. The importance of stand history in natural fuel prediction as found by Muraro (1971), was also experienced to some degree in the present study. The highly variable nature of fire in Muraro's study area in British Columbia, compared to eastern Colorado Front Range lodgepole pine stands where stand replacing crown fires are the rule rather than the exception, is believed to be the reason for the differences in the two study results.

The evaluation tests of the regressions using local data extracted from the literature were very positive overall. Predicted values fell within the expected range of variation, with one exception. The consistently high predictions of duff loading indicate that the bulk density value used to compute loading may not be appropriate. The value found in Brown (1974a) based on destructive sampling in northwestern Wyoming may not be representative of Colorado conditions.

Estimating fuels throughout the life cycle of a lodgepole pine stand will require the use of simulation techniques and forest mensuration dynamic models (e.g., Myers 1973; Stage 1973) that account for resulting stand changes and development (mortality and growth) over time as first suggested by Smith (1968) and elaborated upon by Muraro (1971).

The developed regressions should prove useful in such a scheme by providing the essential link between fuels and stand characteristics.

## Live Crown Length Prediction

Characteristic live crown length (LCL) was best related to the mean stand D.B.H. Muraro (1971) also found LCL correlated best with D.B.H. The curvilinear regression fitted the data extremely well. A small amount of additional sampling is needed to confirm or deny the leveling off trend beyond approximately 8.5 inches D.B.H. In the evaluation test, the predicted length was within the expected degree of variation.

## Shrub Weight Prediction

Lack of a better fit in the regression equations for estimating kinnikinnick and whortleberry weights can be attributed to: (1) expected variation within a coverage class and (2) the occurrence of herbaceous vegetation in sample collections. Brown and Marsden (1976) developed a second degree polynominal equation with an $R^2$ of 0.91 for estimating kinnikinnick fuel weights in western Montana and northern Idaho. In their study, however, the average plant was always greater than four inches, and pinegrass (*Calamagrostis rubescens* Buck.) was present as a major component in 84 percent of sampled stands. These two factors probably account for the difference in coefficients between the two equations. Thus, the equation presented in Chapter 4 with an $R^2$ of 0.82 is recommended for Colorado conditions.

Of the twenty-five shrubs for which Brown (1976b) developed linear regressions to estimate total aboveground biomass from a tally of basal stem diameters, all but two exhibited $R^2$ values of 0.84 or better. Grouse

whortleberry was one exception having an $R^2$ of 0.62. Considering degree of precision versus time allocated, the percent cover x average height method presented in Chapter 4 is preferable to a tally of basal stems.

The regression equations developed provide a convenient, nondestructive, relatively precise method for estimating shrub fuel weights of kinnikinnick and whortleberry. Fuel weights of the two shrubs can be determined in conjunction with other resource inventories by simply making ocular estimates of percent cover and/or measurements of average shrub height in a series of systematically spaced quadrats. Thirty quadrats per acre in kinnikinnick stands and ten per acre in whortleberry will often hold sampling errors to 25 percent.

## Dwarf Mistletoe Parasitism Effects

The loading of downed woody fuel size classes less than three inches in diameter was not consistently higher and dead fuel depth was only slightly higher in the heavily infested stands than in the less infested stands. Findings from *t* test analysis indicate that distance to live crown base (DLCB) was the only consistent, significantly different fuel characteristic. DLCB was lower in the heavily infested stands. This is due to the stagnating affect that dwarf mistletoe exerts on stem height and growth development. Lower DLCB, higher stem density and higher crown bulk density in the heavily infested stands would result in greater susceptibility to crown fire initiation and spread.

The investigation reported in this thesis is the first to quantitatively assess fuels in relation to dwarf mistletoe incidence in lodgepole pine. Effects on the surface fuel strata are inconclusive because of the limited number of stands sampled. Dwarf mistletoe appears to enhance crown fire potential through its influence on the aerial fuel

strata. Further sampling over a much broader range of stand and infestation conditions is needed in order to clearly define the effects of dwarf mistletoe parasitism on the fuel complex. In addition to the 6-class dwarf mistletoe rating and percentage of infested stems, time since infestation should be documented.

## Application of Results

Eastern Colorado Front Range land management agencies require fuels information for a variety of purposes. In the event that time and manpower do not permit fuel inventories, the present study results should provide sufficient precision to meet general and specific information needs in lodgepole pine fuel and fire management programs. Estimation of fuel characteristics may employ a combination of inventory and prediction.

Users must keep in mind the limitations imposed by sampled stand conditions and the study area involved. The developed relationships cannot be expected to be valid if extrapolated beyond the range encountered in this study.

Study results will have applications in not only natural fuel complexes but also in slash complexes of silviculturally-created debris and existing residues. Natural fuel characteristics can be estimated from timber stand inventories using the regression equations, and/or approximated from site information for use in assessing fire potential in and near mountain residential areas (Hulbert 1972), in preparing preattack plans for drainages, in fuel management decision making on timber sale areas and precommercial thinning sites, and with inclusion of natural residues in modeling actual and simulated potential fire behavior in silviculturally-created slash fuel complexes (Albini and others

1977). In addition to traditional broadcast burning of slash residues, study results should have use as background information on fuel complexes and in the planning stages of prescribed fire use in standing timber for fuel reduction, insect and disease control, thinning, type conversion, and forest vegetation enhancement (Alexander and Hawksworth 1975; Butts et al. 1976; Moir 1972; Muraro 1978a, 1978b).

Basal area can readily be estimated by a forester but what does a ton of fuel look like? The photo series should help land managers to familiarize themselves with fuel tonnages.

In more general terms, the study will also prove useful in the evaluation of and comparison to existing National Fire-Danger Rating System fuel models that resemble lodgepole pine fuel complexes (Deeming and Brown 1975), as input into future natural fuel appraisal schemes (Kiil 1967b, 1968) including considerations of crown fire potential, and as basic environmental information in land use planning.

Perhaps the most immediate application afforded by the reconnaissance sampling of fuel and stand conditions in this study will be in education and knowledge. The quantitative results of the present study should improve communication and understanding of lodgepole pine fuel complexes. Hopefully land managers will be aided by this thesis in making more intelligent and objective decisions.

## Recommendations on Future Research

Fuel description science and technology has never had a history of being static. Improvements in the present study results are acknowledged. Future research in the eastern Colorado Front Range should attempt to expand upon results obtained to date.

Many research needs have been noted throughout this chapter. The following recommendations on future research, listed in order of priority, are based on the author's experience with the present study:

1. Relate duff weight to depth and/or determine a representative bulk density value(s).

2. Sample fuel, stand, and site characteristics in approximately five stands each in the 20 to 60 and 175 to 250 age-class ranges.

3. Attempt to relate dead fuel depth to downed woody fuel loading.

4. Determine representative physical properties used in loading calculations for each downed woody fuel size class.

Several of the research needs noted in this chapter and recommendations 1, 3 and 4 could be done concurrently with recommendation 2. This arrangement would avoid having numerous separate studies.

The justification for recommendation 1 was substantiated in the evaluation test of the duff loading regression. Muraro (1971) has shown that a reasonably good fit relating forest floor weight to depth can be obtained for lodgepole pine.

Data on a few immature and mature to over-mature stands need to be gathered in order to resolve and confirm developed relationships near the end points of the lodgepole pine fuel complex life cycle. The question of duff depth after 175 years and live crown length beyond 8.5 inches D.B.H. are two cases in point.

Albini and Brown (1978) have related fuel depth to loading in lodgepole pine fuel complexes. Corresponding research should begin in natural fuel complexes.

Specific gravities, squared quadratic-mean-diameters and correction factors for vertical orientation bias need to be determined for each

downed woody fuel size class rather than continually relying on properties determined in the Northern Rocky Mountains. Anderson (1978) has suggested that greater accuracy in loading estimates can be obtained by utilizing local figures for specific gravity. Adaptation of the planar intersect method to all Southern Rocky Mountain tree species is recommend. Ryan and Pickford (1978) have recently completed a partial adaptation for seven tree species, including lodgepole pine, in the Blue Mountains of Oregon and Washington.

Three points that extend beyond the direct context of the present study but are nevertheless relevant are: (1) fire effects studies document fuel development in addition to vegetation response, and (2) a standard technique for evaluating dead branches on stem boles (e.g., Lawson 1972; Muraro 1971) should be developed, and (3) reference fuel loadings versus qualitative fire potential in natural fuel complexes, as suggested by Dr. James K. Brown (*in* Aldrich and Mutch 1973), need to be established.

# BIBLIOGRAPHY

# BIBLIOGRAPHY


Aho, Paul E. 1974. Decay. p. Q-1 - Q-17, *In* Environmental Effects of Forest Residues Management in the Pacific Northwest: a state-of-knowledge compendium (Owen P. Cramer, organizer and tech. ed.). USDA For. Serv. Gen. Tech. Rep. PNW-24. PNW For. and Range Exp. Stn., Portland, Oreg.

Albini, Frank A. 1975. A computer algorithm for sorting field data on fuel depths. USDA For. Serv. Gen. Tech. Rep. INT-23, 25 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Albini, Frank A., and James K. Brown. 1978. Predicting slash depth for fire modeling. USDA For. Serv. Res. Pap. INT-206, 22 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Albini, Frank A., and others. 1977. Users' guide to debris prediction and hazard appraisal. USDA For. Serv., North. Reg., misc. publ., 34 p. Missoula.

Aldrich, David F., and Robert W. Mutch. 1973. Wilderness fire management: planning guidelines and inventory procedures. USDA For. Serv., North. Reg., misc. publ., 36 p. + appendices. Missoula, Mont.

Alexander, Martin E. 1974. Fuel, vegetative, and topographic data analysis by habitat and timber types of stands w/in the Rolling Land Form ELU, Bear Creek Fire Management Unit. Unpublished report on file with USDA For. Serv., Nezperce Natl. For., Moose Creek Ranger Dist., Grangeville, Idaho. 13 p.

Alexander, Martin E. 1978. Photo series of natural residues and conditions in Colorado lodgepole pine fuel complexes. Colo. State Univ., Coll. Forest. and Nat. Resour., Dep. For. and Wood Sci., Fire Sci. and Tech. Prog., Fort Collins. 48 p.

Alexander, Martin E., and Frank G. Hawksworth. 1975. Wildland fires and dwarf mistletoes: a literature review of ecology and prescribed burning. USDA For. Serv. Gen. Tech. Rep. RM-14, 12 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Alexander, Martin E., and David V. Sandberg. 1976. Fire ecology and historical fire occurrence in the forest and range ecosystems of Colorado: a bibliography. Colo. State Univ., Coll. Forest. and Nat. Resour., Dep. For. and Wood Sci. Occas. Pap., 17 p. Fort Collins.

Alexander, Martin E., David V. Sandberg, and Jack S. Barrows. 1976. Progress report no. 2: quantitative description of fuels and fire behavior potential in even-aged lodgepole pine forests of the Colorado Front Range. Colo. State Univ., Coll. Forest. and Nat. Resour., Dep. For. and Wood Sci., Fire Sci. and Tech. Prog., Fort Collins. 68 p.

Alexander, Robert R. 1966. Site indexes for lodgepole pine, with corrections for stand density: instructions for field use. U.S. Dep. Agric. For. Serv. Res. Pap. RM-24, 7 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Alexander, Robert R. 1974. Silviculture of subalpine forests in the central and southern Rocky Mountains: the status of our knowledge. USDA For. Serv. Res. Pap. RM-121, 88 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Almeida, Ricardo. 1969. Understory vegetation of lodgepole pine. M.S. Thesis, Univ. Wyo., Laramie. 51 p.

Anderson, Hal. E. 1974. Appraising forest fuels: a concept. USDA For. Serv. Res. Note INT-187, 10 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Anderson, Hal E. 1975. Problem analysis of fuel appraisal. Unpublished report on file with USDA For. Serv., Intermt. For. and Range Exp. Stn., North. For. Fire Lab., Res. Work Unit FS-INT-2104, Missoula, Mont. 25 p.

Anderson, Hal E. 1978. Graphic aids for field calculation of dead, down forest fuels. USDA For. Serv. Gen. Tech. Rep. INT-45, 20 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Anonymous. 1967. Forest cover types of North America (exclusive of Mexico). Soc. Amer. Foresters, Washington, D.C. 67 p.

Avery, T. Eugene. 1967. Forest measurements. Ed. 1, 290 p. McGraw-Hill, N.Y.

Beaufait, William R. 1971. Fire and smoke in Montana forests. p. 1-23, *In* Forest Land Use and the Environ., (R.M. Weddle, ed.). Univ. Mont., Missoula.

Brickell, James E. 1970. Equations and computer subroutines for estimating site quality of eight Rocky Mountain species. USDA For. Serv. Res. Pap. INT-75, 22 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Brown, Arthur A., and Kenneth P. Davis. 1973. Forest fire: control and use. Ed. 2, 686 p. McGraw-Hill, N.Y.

Brown, James K. 1966. Forest floor fuels in red and jack pine stands. USDA For. Serv. Res. Note NC-9, 4 p. North Cent. For. Exp. Stn., St. Paul, Minn.

Brown, James K. 1971. A planar intersect method for sampling fuel volume and surface area. For. Sci. 17:96-102.

Brown, James K. 1972. Fuel inventory and appraisal. Paper presented at the USDA For. Serv. Natl. Fire-Danger and Fire-Weather Seminar [Nov. 14-16, Missoula, Mont.]. 9 p.

Brown, James K. 1974a. Reducing fire potential in lodgepole pine by increasing timber utilization. USDA For. Serv. Res. Note INT-181, 6 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Brown, James K. 1974b. Fuel and vegetation inventory procedures--White Cap Study. Unpublished report on file with USDA For. Serv., Intermt. For. and Range Exp. Stn., North. For. Fire Lab., Res. Work Unit FS-INT-2104, Missoula, Mont. 11 p.

Brown, James K. 1974c. Handbook for inventorying downed woody material. USDA For. Serv. Gen. Tech. Rep. INT-16, 25 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Brown, James K. 1975. Fire cycles and community dynamics in lodgepole pine forests. p. 429-155, *In* Manage. Lodgepole Pine Ecosyst. Symp. [Oct., 1973, Pullman, Wash.]. Proc., 2 vols. David M. Baumgarter, ed.). Wash. State Univ., Pullman.

Brown, James K. 1976a. Predicting crown weights for 11 Rocky Mountain conifers. p. 101-115, *In* Int. Union of Forest. Res. Organ., S4.01 Mensuration, Growth and Yield, Working Parting on the Mensuration of the For. Biomass Proc. [June 22, Oslo, Norway]. Coll. of Life Sci. and Agric., Univ. Maine, Orono.

Brown, James K. 1976b. Estimating shrub biomass from basal stem diameters. Can. J. For. Res. 6: 153-158.

Brown, James K. 1978. Weight and density of crowns of Rocky Mountain conifers. USDA For. Serv. Res. Pap. INT-197, 56 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Brown, James K., and Michael A. Marsden. 1976. Estimating fuel weights of grasses, forbs, and small woody plants. USDA For. Serv. Res. Note INT-210, 11 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Brown, James K., and Peter J. Roussopoulos. 1974. Eliminating biases in the planar intersect method for estimating volumes of small fuels. For. Sci. 20: 350-356.

Brown, James K., J.A. Kendall Snell, David L. Bunnell. 1977. Handbook for predicting slash weight of western conifers. USDA For. Serv. Gen. Tech. Rep. INT-37, 35 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Butts, David B., Harry B. Clagg, and David R. Stevens. 1976. Fire management in Rocky Mountain National Park. Proc. Tall Timbers Fire Ecol. Conf. 14: 59-86.

Clagg, Harry B. 1975. Fire ecology in high-elevation forests in Colorado. M.S. Thesis, Colo. State Univ., Fort Collins. 137 p.

Clements, F.C. 1910. The life history of lodgepole burn forests. U.S. Dep. Agric. For. Serv. Bull. 79, 56 p. Washington, D.C.

Daubenmire, R. 1976. The use of vegetation in assessing the productivity of forest lands. Bot. Rev. 42: 115-143.

Davis, Kenneth P. 1966. Forest management: regulation and valuation. Ed. 2, 519 p. McGraw-Hill, N.Y.

Deeming, John E., and James K. Brown. 1975. Fuel models in the National Fire-Danger Rating System. J. Forest 73: 347-350.

Deeming, John E., Robert E. Burgan, and Jack D. Cohen. 1977. The National Fire-Danger Rating System--1978. USDA For. Serv. Gen. Tech. Rep. INT-39, 63 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Dickinson, C.H., and G.J.F. Pugh (eds.) 1974. Biology of plant litter decomposition-Volume 1. 146 p. Acad. Press, London.

Dieterich, John H. 1977. Problem analysis: problem 1-fuel management on commercial timberlands of the central Rocky Mountains and southwest. Unpublished report on file with the USDA For. Serv., Rocky Mt. For. and Range Exp., Forest. Sci. Lab., Res. Work Unit FS-RM-2108, Tempe, Ariz. 21 p.

Draper, N.R., and H. Smith. 1966. Applied regression analysis. John Wiley & Sons, Inc., N.Y. 407 p.

Dyrness, C.T. 1973. Early stages of plant succession following logging and burning in the western Cascades of Oregon. Ecology 54: 57-69.

Fahnestock, George R. 1960. Logging slash flammability. U.S. Dep. Agric. For. Serv., Intermt. For. and Range Exp. Stn. Res. Pap. 58, 67 p. Ogden, Utah.

Fahnestock, George R. 1976. Fires, fuels, and flora as factors in wilderness management: the Pasaysten case. Proc. Tall Timbers Fire Ecol. Conf. 15: 33-69.

Fahnestock, George R. 1977. Interactions of forest fire, flora, and fuels in two Cascade Range Wilderness areas. Ph.D. Diss., Univ. Wash., Seattle. 179 p. (Diss. Abstr. Int. 38: 2451-B)

Fosberg, Michael A. 1970. Drying rates of heartwood below fiber saturation. For. Sci. 16: 57-63.

Gary, Howard L. 1976. Crown structure and distribution of biomass in a lodgepole pine stand. USDA For. Serv. Res. Pap. RM-165, 20 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Hawkes, Brad C. 1978. A fire history and fuel appraisal study of Kananaskis Provincial Park. Cont. Rep. submitted to Alta. Rec., Parks and Wildl., Prov. Parks Div., Resour. Assess. and Manage. Sec., Edmonton, Alta. 20 p. + appendices.

Hawksworth, Frank G. 1977. The 6-class dwarf mistletoe rating system. USDA For. Serv. Gen. Tech. Rep. RM-48, 7 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Horton, K.W. 1953. Causes of variation in stocking of lodgepole pine following fire. Can. Dep. North Aff. and Nat. Resour., Forest. Br., For. Res. Div. Silvic. Leafl. 95, 4 p. Ottawa, Ont.

Horton, K.W. 1955. Early developments in a subalpine lodgepole pine stand of fire origin. Can. Dep. North. Aff. and Nat. Resour., Forest. Br., For. Res. Div. Tech. Note 67, 26 p. Ottawa, Ont.

Hulbert, James. 1972. Fire problems in rural suburbs. Amer. For. 78(2): 24-27, 47.

Hutchings, Selar S., and Jack E. Schmautz. 1969. A field test of the relative-weight-estimate method for determining herbage production. J. Range Manage. 22: 408-411.

Jeske, Bruce W., and Collin D. Bevins. 1976. Spatial and temporal distribution of natural fuels in Glacier Park. Paper presented at the 1st Conf. Sci. Res. Natl. Parks [Nov. 9-13, New Orleans, La.]. 20 p.

Johnstone, W.D. 1970. Component dry weights of 100-year-old lodgepole pine trees. Dep. Fish. and Forest., Can. Forest. Serv. Inform. Rep. A-X-31, 14 p. For. Res. Lab., Calgary, Alta.

Johnstone, W.D. 1971. Total standing crop and tree component distributions in three stands of 100-year-old lodgepole pine. p. 81-89, *In* Forest Biomass Studies, IUFRO Sec. 25, Growth and Yield, Working Group on Forest Biomass Studies. Univ. Maine, Coll. Life Sci. and Agric., Orono. [XVth IUFRO Cong., Gainsville, Fla., March 15-20]

Kessell, Stephen R., Meredith W. Potter, Collin D. Bevins, Larry Bradshaw, and Bruce W. Jeske. 1978. Analysis and application of forest fuels data. Environ. Manage. 2: 347-363.

Kiil, A.D. 1965. Weight and size distribution of slash of white spruce and lodgepole pine. Forest Chron. 41: 432-437.

Kiil, A.D. 1967a. Fuel weight tables for white spruce and lodgepole pine crowns in Alberta. Can. Dept. Forest. and Rural Devel., Forest. Br., Dept. Publ. 1196, 13 p. Ottawa, Ont.

Kiil, Ain David. 1967b. The fuel complex in 70-year-old lodgepole pine stands of different densities. M.S. Thesis, Univ. Mont., Missoula. 62 p.

Kiil, A.D. 1968. Weight of the fuel complex in 70-year-old lodgepole pine stands of different densities. Can., Dep. Forest. and Rural Devel., Forest. Br. Dep. Publ. 1228, 9 p. Ottawa, Ont.

Kiil, A.D. 1971. Estimating weights of tree components of lodgepole pine from large-scale aerial photographs. Can. J. For. Res. 1: 193-194.

Krugman, Stanley L., and James L. Jenkinson. 1974. Pinus L. Pine. p. 598-638, *In* Seeds of Woody Plants in the United States, C.S. Schopmeyer (tech. coord.). USDA, Agric. Handb. 450, 883 p. Washington, D.C.

Lawson, Bruce D. 1972. Fire spread in lodgepole pine stands. M.S. Thesis, Univ. Mont., Missoula. 119 p. (Also available as Can. Forest. Serv. Int. Rep. B.C.-36. Pac. For. Res. Cent., Victoria, B.C.)

Lyman, C.K. 1945. Principles of fuel reduction for the northern Rocky Mountain region (progress report 1). U.S. Dep. Agric. For. Serv., North. Rocky Mt. For. and Range Exp. Stn., misc. publ., 98 p. Missoula, Mont.

Lyon, L. Jack. 1977. Attrition of lodgepole pine snags on the Sleeping Child Burn, Montana. USDA For. Serv. Res. Note INT-219, 4 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

McFee, W.W., and E.L. Stone. 1966. The persistence of decaying wood in the humus layer of northern forests. Proc. Soil Sci. Amer. 30: 513-516.

Marr, John W. 1961. Ecosystems of the east slope of the Front Range in Colorado. Univ. Colo. Stud. Serv. Biol. 8, 134 p. Boulder, Colo.

Martin, Robert E., Dan D. Robinson, and Walter H. Schaeffer. 1976. Fire in the Pacific Northwest--perspectives and problems. Proc. Tall Timbers Fire Ecol. Conf. 15: 1-23.

Mason, D.T. 1915. The life history of lodgepole pine in the Rocky Mountains. U.S. Dep. Agric. Bull. 154, 35 p. Washington, D.C.

Mathews, Edward E. 1975. The accretion of fuel in lodgepole pine forests in southwestern Montana. Unpublished report on file with the USDA For. Serv., Intermt. For. and Range Exp. Stn., North. For. Fire Lab., Study Plan 2108-25, 17 p. + appendix. Missoula, Mont.

Moir, William H. 1969. The lodgepole pine zone in Colorado. Amer. Midl. Nat. 81: 87-98.

Moir, William H. 1972. Litter, foliage, branch, and stem production in contrasting lodgepole pine habitats of the Colorado Front Range. p. 189-198, *In* Symp. Res. Conf. For. Ecosyst. Proc. [Mar., Bellingham, Wash.] USDA For. Serv., Pac. Northwest For. and Range Exp. Stn., Portland, Oreg.

Moir, W.H., and H. Brier. 1969. Weight and nitrogen, phosphorus, potassium and calcium content of forest floor humus of lodgepole pine stnads in Colorado. Proc. Soil Sci. Amer. 33: 137-140.

Muraro, S.J. 1964. A method of measuring fire rate-of-spread in extracted samples of ground vegetation. Can. Dep. Forest. Publ. 1081, 11 p. Ottawa, Ont.

Muraro, S.J. 1966. Lodgepole pine logging slash. Can. Dep. Forest. Publ. 1153, 14 p. Ottawa, Ont.

Muraro, S.J. 1971. The lodgepole pine fuel complex. Dep. Fish. and Forest., Inform. Rep. BC-X-53, 20 p. + appendices. For. Res. Lab., Victoria, B.C.

Muraro, S.J. 1978a. Prescribed fire--a tool for the control of dwarf mistletoe in lodgepole pine. p. 124-127, *In* Proc. Symp. Dwarf Mistletoe Control Through Forest Management (Robert F. Scharpf and John R. Parmeter, Jr., tech. coords.). USDA For. Serv. Gen. Tech. Rep. PSW-31. Pac. Southw. For. and Range Exp. Stn., Berkely, Calif.

Muraro, S.J. 1978b. The use of prescribed fire in the management of lodgepole pine. p. 82-89, *In* Fire Ecol. Resour. Manage. Workshop Proc. (D.E. Dube, comp.). Environ. Can., Can. Forest. Serv. Inform. Rep. NOR-X-210. North. For. Res. Cent., Edmonton, Alta.

Myers, Clifford A. 1967. Yield tables for managed stands of lodgepole pine in Colorado and Wyoming. USDA For. Serv. Res. Pap. RM-26, 20 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Myers, Clifford A. 1973. Simulating changes in even-aged timber stands. USDA For. Serv. Res. Pap. RM-109, 47 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Myers, Clifford A., Frank G. Hawksworth, and James L. Stewart. 1971. Simulating yields of managed, dwarf mistletoe-infested lodgepole pine stands. USDA For. Serv. Res. Pap. RM-72, 15 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Nordin, V.J. 1954. Forest pathology in relation to the management of lodgepole pine in Alberta. Forest. Chron. 30: 299-308.

Oberheu, Rick D., and Patrick F. Hartless. 1975. Handbook for inventory surface fuels. Unpublished report on file with the USDA For. Serv., Intermt. For. and Range Exp. Stn., North. For. Fire Lab., Fire Mult. Use Manage. RD & A Prog., Missoula, Mont. 31 p.

Oberheu, Rick D., and Robert W. Mutch. 1975. Summary of Teton wilderness by fuels, vegetation, topography, rate-of-spread, intensity and burnout potential. Appendix D (42 p.), *In* Teton Wilderness Fire Manage. Plan. USDA For. Serv., Bridger-Teton Ntal. For., Jackson, Wyo.

Pickford, Stewart G., George R. Fahnestock, and Roger Ottmar. 1977. Fuels, weather, and lightning fires in the Olympic National Park. Univ. Wash., Coll. For. Resour., Seattle. 92 p.

Peirce, Thomas L. 1977. Development of a computerized natural fuels data bank for western coniferous forests. M.S. Thesis, Colo. State Univ., Fort Collins. 109 p.

Phillips, T.A. 1973. The effects of fire on vegetation and wildlife on a lodgepole pine burn in Chamberlain Basin, Idaho. U.S. Dept. Agric., For. Serv., Intermt. Reg. Range Improv. Notes 18(1): 1-9. Ogden, Utah.

Reynolds, James F. 1971. Moisture interception of lodgepole pine and spruce-fir litter in southeastern Wyoming. M.S. Thesis, Univ. Wyo., Laramie. 48 p.

Ryan, Kevin C., and Stewart G. Pickford. 1978. Physical properties of woody fuels in the Blue Mountains of Oregon and Washington. USDA For. Serv. Res. Note PNW-315, 10 p. Pac. Northw. For. and Range Exp. Stn., Portland, Oreg.

Sando, Rodney W., and Charles H. Wick. 1972. A method of evaluating crown fuels in forest stands. USDA For. Serv. Res. Pap. NC-84, 10 p. North Cent. For. Exp. Stn., St. Paul, Minn.

Smith, J. Harry G. 1968. Simulation of forest fuels. Paper presented at the Forest. Sect., Northw. Sci. Assoc. Ann. Meet. [Mar. 22-23, Ellensburg, Wash.] 7 p.

Smithers, L.A. 1961. Lodgepole pine in Alberta. Can. Dep. Forest., For. Res. Br. Bull. 127, 153 p. Ottawa, Ont.

Snedecor, George W. and William G. Cochran. 1967. Statistical methods. Ed. 6, 593 p. Iowa State Univ. Press., Ames.

Sneeuwjagt, Richard J. 1974. Evaluation of the grass fuel model of the national fire danger rating system. M.S. Thesis, Univ. Wash., Seattle. 162 p.

Stage, Albert R. 1973. Prognosis model for stand development. USDA For. Serv. Res. Pap. INT-37, 32 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Stahelin, R. 1943. Factors influencing the natural restocking of high altitude burns by coniferous trees in the central rocky mountains. Ecology 24: 19-30.

Steen, Ordell A., and Ralph L. Dix (in prep.) A phytosociological classification of subalpine forests of the southern Rocky Mountains.

Tackle, David. 1959. Silvics of lodgepole pine. U.S. Dep. Agric. For. Serv., Intermt. For. and Range Exp. Stn., Misc. Publ. 19, 24 p. Ogden, Utah. (Rev. 1961)

Tisdale, E.W. 1950. Grazing of forest lands in interior British Columbia. J. Forest. 48: 856-860.

Trappe, James M., and Robert W. Harris. 1958. Lodgepole pine in the Blue Mountains of northeastern Oregon. U.S. Dep. Agric. For. Serv., Pac. Northwest For. and Range Exp. Stn., Res. Pap. 30, 22 p. Portland, Oreg.

Trimble, G.R., Jr., and Norman R. Tripp. 1949. Some effects of fire and cutting on forest soils in the lodgepole pine forests of the Northern Rocky Mountains. J. Forest. 47: 640-642.

U.S. Forest Products Laboratory. 1955. Wood handbook. U.S. Dep. Agric., Agric. Handb. 72, 528 p. (Rev. Aug. 1974, n.p.).

USDA Forest Service. 1974a. Compartment prescription handbook. USDA For. Serv. FSH Handb. 2409.21d (Region 2 amendment no. 2), Rocky Mt. Reg., Denver, Colo. n.p.

USDA Forest Service 1974b. National fuel classification and inventory system--preliminary draft. USDA For. Serv., Div. Fire Manage., Washington, D.C. 23 p. + appendices.

Van Wagner, C.E. 1968. The line intersect method in forest fuel sampling. For. Sci. 14: 20-26.

Van Wagner, C.E. 1977. Conditions for the start and spread of crown fire. Can. J. For. Res. 7: 23-24.

Wallmo, Olof C., Wayne L. Regelin, and Donald W. Reichert. 1972. Forage use by mule deer relative to logging in Colorado. J. Wildl. Manage. 36: 1025-1033.

# APPENDICES

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Appendix A.-- *Field Data Forms.*

STAND & SITE INFORMATION FORM

Stand Number:_____ Fuel Transect Nos.:_____to_____ Date:_____

Legal Description:_____Twn._____Rge._____Sec._____1/4 Sec._____40.

Administrative Unit:_____

Elevation:_____Physiographic Site:_____Slope Configuration:_____

Phytosociological Classification:_____Division_____Type_____Phase

Stand Conditions

Regeneration:_____

Shrubs:_____

Branching Habit & Vertical Fuel Continuity:_____

_____

Crown Classes:_____

Fire History:_____

Factors Influencing Surface Fuel Conditions:_____

_____

_____

Additional Comments:_____

_____

_____

_____

_____

_____

_____

_____

_____

OVERSTORY TALLY FORM

Stand Number: _____ Overstory Plot Number: _____

Plot type:_____10 BAF Variable____ 1/300-acre Fixed_____1/10-acre Fixed

(denote site index dominants with asterisk*)

| Stem No. | Tree Species | Condition Class | D.B.H. | Height | DLCB | LCL | DMR |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

# FOREST FLOOR & SURFACE FUEL INVENTORY FORM

Stand Number: _____ Fuel Transect Plot Number: _____

Aspect: _____ Terrain Slope: _____ Planar Slope: _____

| No. Intersections <3.0 Inches in Diameter | | | |
|---|---|---|---|
| 12 ft. Transect | | | 15 ft.-Transect |
| <0.25 | 0.25-0.99 | cones | 1.0-2.99 |
| | | | |

| Diameter Intersections >3.0 Inches - 50 ft.-Transect | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Sound | | | | | | | | | | |
| | | | | | | | | | | |
| Rotten | | | | | | | | | | |
| | | | | | | | | | | |

| Dead Fuel Depth | | | | | | Live Fuel Depth | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | |

| Understory Vegetation | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| % Standard | | | | % Dead | | | | Base | | |
| 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | cover | height | weight |
| | | | | | | | | | | |

| Litter | | | | | Duff Depth | | | |
|---|---|---|---|---|---|---|---|---|
| % Standard | | | | Base Weight | 1 | 2 | 3 | 4 |
| | | | | | | | | |
| | | | | | | | | |

Comments: _____

Appendix B.-- *Summary of Fuel and Stand Equations Utilized.*

## Fuel Loadings

Woody Surface Fuels:

$$W = \frac{11.64 \cdot nd_q^2 \text{ or } \Sigma d^2 \cdot s \cdot \alpha \cdot c}{N \cdot \ell}$$ (Reference: Brown 1974c)

Where

$W$ = fuel loading, T/A
$11.64$ = a constant to convert volume to T/A
$nd_q^2$ = number of size class intercepts less than 3.0 inches in diameter times respective squarded quadratic-mean diameter, $in^2$.
$\Sigma d^2$ = sum of squared diameters for intercepts 3.0 inches and greater in diameter, $in^2$.

$s$ = specific gravity of fuel size class, g/cc
$\alpha$ = correction factor for nonhorizontal angle of fuel particles
$c$ = slope correction factor ($c = \sqrt{1 + [\text{Percent Slope}/100]^2}$ )
$N$ = number of fuel transects
$\ell$ = length of the sampling plane per fuel transect, ft.

Duff:

$$W = 21.78 \cdot \rho_b \cdot \delta$$

Where

$W$ = duff loading, T/A
$21.78$ = a constant to convert $lbs./ft^2$ to T/A
$\rho_b$ = duff bulk density, $lbs./ft^3$
$\delta$ = duff depth, ft.

Litter:

$$W = 21.78 \cdot [(P_1 + P_2 + P_3 + P_4/4)/100] \cdot w_B$$

Where

$W$ = litter loading, T/A
$21.78$ = a constant to convert $lbs./ft^2$ to T/A
$P_1 etc$ = midpoint of percentage class assigned to respective relative-estimate quadrat (the "standard" is assigned 100 percent)
$w_B$ = base weight of "standard", $lbs./ft^2$

Understory Vegetation: $W_t = 21.78 \cdot [(P_1 + P_2 + P_3 + P_4)/100] \cdot (w_B/2)$

Where

$W_t$ = loading of total understory vegetation, T/A
21.78 = a constant to convert lbs./ft$^2$ to T/A
$P_1 etc$ = midpoint of percentage class assigned to respective relative-estimate quadrat (the "standard" is assigned 100 percent)
$w_B$ = base weight of "standard", lbs./ft$^2$

$W_d = [(P_1 + P_2 + P_3 + P_4/4)/100] \cdot W_t$

Where

$W_d$ = loading of dead understory vegetation, T/A
$P_1 etc$ = midpoint of percentage class of dead material found in each relative-estimate quadrat
$W_t$ = loading of total live understory vegetation, T/A

$W_L = W_t - W_d$

Where

$W_L$ = loading of live understory vegetation, T/A
$W_t$ = loading of total understory vegetation, T/A
$W_d$ = loading of dead understory vegetation, T/A

## Stand Structure and Site

Basal Area:

$BA = n \cdot 10$ [for variable plot] (Reference: Avery 1967)

*or*

$= \Sigma D.B.H. \cdot d$ [for fixed plots]

Where

BA = basal area, ft$^2$/A
n = number of count stems in 10 BAF plot
D.B.H. = area of stem diameter-at-breast height, ft$^2$
d = denominator of fixed plot size (300 or 10)

Density:

$D = BA/BA_s$ [for variable plot] (Reference: Davis 1966)

*or*

$= n \cdot d$ [for fixed plots]

Where

D = density, no./A
BA = basal area, $ft^2$/A
$BA_s$ = area of average stand stem D.B.H., $ft^2$
n = number of count stems in fixed plot
d = denominator of fixed plot size (300 or 10)

Spacing: $S = \sqrt{43,560/D}$ (Reference: Davis 1966)

Where

S = average spacing between stems, ft.
D = density of stems, no./A

Volume: $V = 16.96 + 0.50\ (BA \cdot H)$ (Reference: Myers 1967)

Where

V = gross stand volume, $ft^3$/A
BA = basal area, $ft^2$/A
H = average stand stem height

Crown Competition Factor:

$CCF = 50.58 + [(5.25 \cdot BA)/D.B.H.]$ (Reference: Alexander 1966)

Where

CCF = crown competition factor
BA = basal area, $ft^2$/A
D.B.H. = average stand stem diameter

Site Index: (Reference: Brickell 1970)

$$SI = H + 18.310745\ (\ln A - 4.6052) + [-.0021973907\ (A^2 - 10000)] + 0.0000061670435\ (A^3 - 1000000) + (-64.32135\ [(H/A) - (H-100)]) + (9528.3711\ [(H/A^2) - (H/10000)]) + (-34848.289\ [H/A^{2.5}) - H/100000)])$$

$$1 - (0.000818867\ [CCF - 125] \cdot [-64.32135\ ((1/A) - 0.01)] + 9528.3711\ [(1/A^2) - 0.0001] + (-34848.289\ [(1/A^{2.5}) - 0.00001]) + 1)$$

Case 1: use top part of equation if CCF < 125

Case 2: use top divided by bottom part of equation if CCF > 125

where

SI = site index at a base age of 100 years
H = mean height of dominant, ft.
A = age, yrs.
CCF = crown competition factor

Appendix C.-- *Selected Field Notes on Sampled Stands.*

The following notes refer to field observations on stands not previously mentioned nor readily discernable from the data presented in Chapter 4.

Medium shrubs such as common juniper and buffalo-berry were the most common, and contributed little to downed woody fuel or litter quantities. These two species averaged one to two feet in height and covered less than ten percent of sampled stand area. Except for the obvious presence of kinnikinnick and whortleberry, understory vegetation consisted principally of arnica, green-flowered pyrola, prince's pine (*Chimaphilia umbellata* L. Bart.), and various sedges (*Carex* spp.).

Observed regeneration was absent to very sparse. Lodgepole pine seedlings less than one foot high were noted in ten stands (01, 02, 05, 06, 10, 11, 16, 20, 23, 24). Douglas-fir seedlings less than six inches in height were observed in two stands (02, 13) and Engelmann spruce regeneration approximately two feet in height was found in stand LP-20. The presence of Engelmann spruce saplings ($\geq$ DBH in height) was confined to higher elevation stands (08, 16, 24).

Dead branches less than one half inch in diameter extending the length of the bole and not occupying the live crown portion were observed in all but two stands. Stands LP-02 and LP-21 were presumably pruned during thinning operations by the Civilian Conservation Corps *ca.* 1934-35.

Horizontal fuel continuity expressed as the percent area covered by burnable material generally exceeded 85 percent except on terrain

slopes exceeding 40 percent and rocky sites. Nearly the entire forest floor is covered by burnable material of some form or another.

Red squirrel activity was most pronounced in 7 stands (02, 05, 06, 13, 17, 18, 22). Other than heavily infested dwarf mistletoe stands including stands LP-05 and LP-10 (dead tops, downed 3.0+ sound material), no noticeable effect of other diseases or insects on fuel quantities was observed except in stand LP-05 were heart rot of fallen trees was observed. Noticeable natural mortality was associated with older stands (LP-06 and LP-20). Suppression mortality was most noticeable in stands LP-02, 09, 20, and 25. Minor snow and/or wind breakage was observed in five stands (09, 12, 15, 18, 20).

Distance between plot centers of the three dwarf mistletoe stand comparisons are as follows:

| Stand Pair | Distance (ft.) |
|---|---|
| LP-23/24 | 120 |
| LP-25/26 | 92 |
| LP-27/28 | 272 |

Large quantities of rotten material greater than 3.0 inches in diameter resulting from the parent, antecedant fire-killed stand was most noticeable in stands LP-01, 15, 23, and 24 and was nearly or totally absent from stands LP-04, 07, 09, 18, 19, 25, and 26.

Appendix D.-- *Basal area and density by diameter-at-breast-height (D.B.H.) size class distribution, and percent dominant/codominant and intermediate/suppressed trees by sampled stand.*

| D.B.H. Size Class Distribution (inches) | Basal Area ($ft.^2/A$) — Stand No. LP-01 | LP-02 | LP-05 | LP-06 | LP-07 | LP-08 | LP-10 | LP-11 | LP-13 | LP-16 | LP-17 | LP-20 | LP-21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| <0.9 | | | | | | | | | | | | | |
| 1.0-1.9 | | | | | | | | | | | 5 | | |
| 2.0-2.9 | 2 | | | | 2.5 | 2.5 | 5 | 5 | 2.5 | 5 | 5 | | 2.5 |
| 3.0-3.9 | 18 | | 5 | 2.5 | | 2.5 | 12.5 | 15 | 10 | 2.5 | 22.5 | 5 | 7.5 |
| 4.0-4.9 | 22 | | 12.5 | 5 | 10 | | 27.5 | 15 | 20 | 10 | 35 | 7.5 | 12.5 |
| 5.0-5.9 | 42 | 22.5 | 17.5 | 7.5 | 7.5 | 12.5 | 32.5 | 25 | 45 | 2.5 | 60 | 20 | 32.5 |
| 6.0-6.9 | 40 | 30 | 12.5 | 10 | 35 | 17.5 | 32.5 | 22.5 | 70 | 15 | 40 | 30 | 35 |
| 7.0-7.9 | 18 | 27.5 | 15 | 7.5 | 30 | 25 | 2 .5 | 17.5 | 37.5 | 12.5 | 20 | 20 | 17.5 |
| 8.0-8.9 | 6 | 17.5 | 7.5 | 15 | 45 | 40 | 17.5 | 10 | 20 | 10 | 7.5 | 15 | 7.5 |
| 9.0-9.9 | | 5 | 7.5 | 22.5 | 25 | 15 | 10 | | | 35 | 5 | 2.5 | 2.5 |
| 10.0-10.9 | | | 2.5 | 12.5 | 17.5 | 7.5 | 10 | | | 25 | | | |
| 11.0-11.9 | | | 10 | 27.5 | 12.5 | 5 | 2.5 | | | 20 | | | |
| 12.0-12.9 | | | 2.5 | 25 | 2.5 | 5 | | | | 7.5 | | | |
| 13.0-13.9 | | | | 12.5 | 5 | | | | | 2.5 | | | |
| 14.0-14.9 | | | | 2.5 | | | | | | | | | |
| 15.0-15.9 | | | | 7.5 | 7.5 | | | | | | | | |
| 16.0-16.9 | | | | 2.5 | 5 | | | | | | | | |
| 17.0-17.9 | | | | | 2.5 | | | | | | | | |
| 20.0-20.9 | | | | 2.5 | | | | | | | | | |
| 21.0-21.9 | | | | 2.5 | | | | | | | | | |
| % Dominant & Codominant Trees | 65 | 80 | 80 | 80 | 80 | 90 | 80 | 80 | 60 | 95 | 30 | 80 | 80 |
| % Intermediate & Suppressed Trees | 35 | 20 | 20 | 20 | 20 | 10 | 20 | 20 | 40 | 5 | 70 | 20 | 20 |

| D.B.H. Size Class Distribution (inches) | Density (#A.) — Stand No. LP-03 | LP-04 | LP-09 | LP-12 | LP-14 | LP-15 | LP-18 | LP-19 | LP-22 | LP-23 | LP-24 | LP-25 | LP-26 | LP-27 | LP-28 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| <0.9 | | | | | | | | | | | | 40 | 200 | 40 | 620 |
| 1.0-1.9 | 1500 | 825 | 525 | 1800 | 525 | 1425 | 1200 | 600 | 2475 | 30 | 410 | 1300 | 1940 | 320 | 2310 |
| 2.0-2.9 | 1500 | 750 | 675 | 2175 | 975 | 1800 | 1125 | 225 | 1875 | 20 | 390 | 1350 | 1120 | 410 | 1010 |
| 3.0-3.9 | 525 | 675 | 600 | 1125 | 675 | 450 | 975 | 375 | 750 | 80 | 360 | 860 | 290 | 520 | 470 |
| 4.0-4.9 | 375 | 600 | 600 | 600 | 300 | 450 | 375 | 600 | 300 | 120 | 410 | 220 | 40 | 370 | 140 |
| 5.0-5.9 | 75 | 75 | 75 | | | 225 | 150 | 600 | | 170 | 160 | 40 | 40 | 130 | 10 |
| 6.0-6.9 | | | 75 | | 150 | | 75 | 75 | | 160 | 90 | 20 | | 110 | |
| 7.0-7.9 | | | | | | | | | | 120 | | | | 10 | |
| 8.0-8.9 | | | | | | | | | | 20 | | | | 10 | |
| 9.0-9.9 | | | | | | | | | | 10 | | | | | |
| % Dominant & Codominant Trees | 0 | 0 | 0 | 0 | 40 | 0 | 0 | 50 | 0 | 30 | 30 | 5 | 0 | 40 | 5 |
| % Intermediate & Suppressed Trees | 100 | 100 | 100 | 100 | 60 | 100 | 100 | 50 | 100 | 70 | 70 | 95 | 100 | 60 | 95 |

Appendix E.-- *Statistics for Regression Equations.*

<0.25 inch size class loading, Y(01), T/A:

$\hat{Y} = 0.07271 + 0.00019\ X(04) + 0.00006\ X(07)$

| Variable | Description | Range | "t" value | Level of significance |
|---|---|---|---|---|
| Y(01) | <0.25 inch size loading (T/A) | 0.145-0.659 | | |
| X(04) | Dead stem density (#/A.) | 0-2300.0 | 6.985 | 0.001 |
| X(07) | Live stem volume ($ft^3$/A.) | 645.7-5368.2 | 3.463 | .003 |

Simple linear correlation coefficients between Y(01) and independent variables are:

X(04) .669 X(07) .076

The correlation between independent variables is: .438 [correlation significant at the .05 level].

ANOVA Table

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Due to regression | 2 | 0.393 | 0.197 | 19.957 |
| Residual | 25 | 0.246 | 0.010 | |
| Total | 27 | 0.639 | | |

Since $F_{0.005}$ with 2/25 df is 6.60, the regression is deemed significant at the 0.005 level.

0.25-0.99 inch size class loading, Y(02), T/A:

$\hat{Y} = 0.02994 + 0.00059\ X(04) + 0.00445\ X(15)$

| Variable | Description | Range | "t" value | Level of significance |
|---|---|---|---|---|
| Y(02) | 0.25-0.99 inch size loading (T/A) | 0.141-2.322 | | |
| X(04) | Dead stem density (#/A.) | 0.0 -2300 | 5.585 | 0.001 |
| X(15) | Stand age (yrs.) | 57-282 | 2.771 | .015 |

Simple linear correlation coefficients between Y(02) and independent variables are:

X(04) .680 X(15) .289

The correlation between independent variables is: .094.

ANOVA Table

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Due to regression | 2 | 5.298 | 2.649 | 17.811 |
| Residual | 25 | 3.718 | 0.149 | |
| Total | 27 | 9.016 | | |

Since $F_{0.005}$ with 2/25 df is 6.60, the regression is deemed significant at the 0.005 level.

1.0-2.99 inch size class loading, Y(03), T/A:

$\hat{Y} = 0.57717 + 0.07835\ X(02) - 0.00032\ X(20)$

| Variable | Description | Range | "t" value | Level of significance |
|---|---|---|---|---|
| Y(03) | 1.0-2.99 inch size class loading (T/A) | 0.134-4.376 | | |
| X(02) | Dead stem basal area ($ft^2/A$) | 0-40.0 | 4.444 | 0.001 |
| X(20) | Dead stem $DBH^2 \cdot$height ($in^2 \cdot ft.$) | 0-3547.7 | 1.873 | .085 |

Simple linear correlation coefficients between Y(03) and independent variables are:

X(02) .634 X(20) -.201

The correlation between independent variables is: .120.

ANOVA Table

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Due to regression | 2 | 19.053 | 9.527 | 10.623 |
| Residual | 23 | 20.626 | 0.897 | |
| Total | 25 | 39.679 | | |

Since $F_{0.005}$ with 2/23 df is 6.73, the regression is deemed significant at the 0.005 level.

3.0 + sound inch size class loading, Y(05), T/A:

$\hat{Y} = -1.41225 + 0.00819\ X(08) + 0.25324\ X(11)$

| Variable | Description | Range | "t" value | Level of significance |
|---|---|---|---|---|
| Y(05) | 3.0 + sound size class loading (T/A) | 0.0-7.258 | | |
| X(08) | Dead stem volume ($ft^3/A$) | 0.0-694.5 | 5.918 | 0.001 |
| X(11) | Live stem DBH (in.) | 1.9-10.6 | 2.721 | .015 |

Simple linear correlation coefficients between Y(05) and independent variables are:

X(08) .754 X(11) .461

The correlation between independent variables is: .211.

ANOVA Table

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Due to regression | 2 | 74.608 | 37.304 | 24.623 |
| Residual | 25 | 37.875 | 1.515 | |
| Total | 27 | 112.483 | | |

Since $F_{0.005}$ with 2/25 df is 6.60, the regression is deemed significant at the 0.005 level.

Cone loading, Y(06), T/A:

$\hat{Y} = 0.07559 + 0.00035\ X(07) + 0.00688\ X(15)$

| Variable | Description | Range | "t" value | Level of significance |
|---|---|---|---|---|
| Y(06) | Cone loading (T/A) | 0.537-3.821 | | |
| X(07) | Live stem volume ($ft^3$/A) | 645.7-5368.2 | 3.044 | 0.006 |
| X(15) | Stand age | 57-282 | 2.516 | .025 |

Simple linear correlation coefficients between Y(06) and independent variables are:

X(07) .573 X(15) .521

The correlation between independent variables is: .315.

ANOVA Table

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Due to regression | 2 | 8.707 | 4.353 | 10.117 |
| Residual | 24 | 10.327 | 0.430 | |
| Total | 26 | 19.034 | | |

Since $F_{0.005}$ with 2/24 df is 6.66, the regression is deemed significant at the 0.005 level.

Litter loading, Y(07), T/A:

$\hat{Y} = 0.32135 + 0.02310\sqrt{X(07)}$

| Variable | Description | Range | "t" value | Level of significance |
|---|---|---|---|---|
| Y(07) | Litter loading (T/A) | 0.507-2.234 | | |
| X(07) | Live stem volume ($ft^3$/A) | 645.7-5368.2 | 3.408 | 0.003 |

Simple linear correlation coefficient between Y(07) and X(07) is: 577.

ANOVA Table

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Due to regression | 1 | 1.799 | 1.799 | 11.621 |
| Residual | 26 | 4.024 | 0.158 | |
| Total | 27 | 5.823 | | |

Since $F_{0.005}$ with 1/26 df is 9.41, the regression is deemed significant at the 0.005 level.

Duff loading, Y(08), T/A:

$\hat{Y} = -0.06390 + 0.37068\ X(15) - 0.00105\ X(15)^2$

| Variable | Description | Range | "t" value | Level of significance |
|---|---|---|---|---|
| Y(08) | Duff loading (T/A) | 0.0-42.634 | | |
| X(15) | Stand age (yrs.) | 57-282 | 5.874 | 0.001 |
| $X(15)^2$ | Stand age (yrs.) squared | -- | 6.438 | .001 |

Simple linear correlation coefficient between Y(08) and X(15) is: .543.

ANOVA Table

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Due to regression | 2 | 3523.714 | 1761.857 | 37.976 |
| Residual | 41 | 1902.138 | 46.394 | |
| Total | 43 | 5425.852 | | |

Since $F_{0.005}$ with 2/41 df is 6.08, the regression is deemed significant at the 0.005 level.

Dead fuel depth, Y(09), inches:

$\hat{Y} = 1.66503 + 0.00054\ X(04) + 0.00032\ X(07)$

| Variable | Description | Range | "t" value | Level of significance |
|---|---|---|---|---|
| Y(09) | Dead fuel depth (in.) | 1.65-3.81 | | |
| X(04) | Dead stem density (#/A) | 0.0-2300.0 | 4.058 | 0.001 |
| X(07) | Live stem volume ($ft^3$/A) | 645.7-5368.2 | 3.775 | .001 |

Simple linear correlation coefficients between Y(09) and independent variables are:

X(04) .373 X(07) .311

The correlation between independent variables is: .438 [correlation significant at the 0.5 level].

ANOVA Table

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Due to regression | 2 | 4.049 | 2.025 | 8.582 |
| Residual | 25 | 5.898 | 0.236 | |
| Total | 27 | 9.947 | | |

Since $F_{0.005}$ with 2/25 df is 6.60, the regression is deemed significant at the 0.005 level.

Live fuel depth, Y(10), inches:

$\hat{Y} = 0.17928 + 0.00806\ X\ (19)$

| Variable | Description | Range | "t" value | Level of significance |
|---|---|---|---|---|
| Y(10) | Live fuel depth (in.) | 0.0-7.35 | | |
| X(19) | Live stem $DBH^2$.Height (In.·ft.) | 22.6-491.0 | 4.663 | 0.001 |

Simple linear correlation coefficient between Y(10) and X(19) is: .675.

ANOVA Table

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Due to regression | 1 | 37.966 | 37.966 | 21.745 |
| Residual | 26 | 45.394 | 1.746 | |
| Total | 27 | 83.360 | | |

Since $F_{0.005}$ with 1/26 df is 9.41, the regression is deemed significant at the 0.005 level.

Duff depth, Y(11), inches:

$\hat{Y} = -0.00405 + 0.02347\ X(15) - 0.00007\ X(15)^2$

| Variable | Description | Range | "t" value | Level of significance |
|---|---|---|---|---|
| Y(11) | Duff depth (in.) | 0.0-2.7 | | |
| X(15) | Stand age (yrs.) | 57-282 | 5.874 | 0.001 |
| $X(15)^2$ | Stand age (yrs.) squared | -- | 6.438 | .001 |

Simple linear correlation coefficient between Y(11) and X(15) is: .543.

ANOVA Table

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Due to regression | 2 | 14.132 | 7.066 | 37.975 |
| Residual | 41 | 7.629 | 0.186 | |
| Total | 43 | 21.761 | | |

Since $F_{0.005}$ with 2/41 df is 6.08, the regression is deemed significant at the 0.005 level.

Understory vegetation loading, Y(12), T/A:

$\hat{Y} = -0.04896 + 0.00101\ X(19)$

| Variable | Description | Range | "t" value | Level of significance |
|---|---|---|---|---|
| Y(12) | Understory vegetation loading (T/A) | 0.0017-1.0502 | | |
| X(19) | Live stem DBH ·height (in.·ft.] | 22.6-491.0 | 4.339 | 0.001 |

Simple linear correlation coefficients between Y(12) and X(19) is: .648.

ANOVA Table

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Due to regression | 1 | 0.595 | 0.595 | 18.823 |
| Residual | 26 | 0.823 | 0.032 | |
| Total | 27 | 1.418 | | |

Since $F_{0.005}$ with 1/26 df is 9.41, the regression is deemed significant at the 0.005 level.

Distance to live crown base (version 1), Y(13), ft.:

$\hat{Y} = -3.03488 + 0.43851\ X(09) + 0.03831\ X(01)$

| Variable | Description | Range | "t" value | Level of significance |
|---|---|---|---|---|
| Y(13) | Distance to live crown base (ft.) | 6.3-30.8 | | |
| X(09) | Live stem height ($ft^3$) | 11.9-55.8 | 7.166 | 0.001 |
| X(01) | Live stem basal area ($ft^2/A$) | 85.1-238.2 | 2.108 | .05 |

Simple linear correlation coefficients between Y(13) and independent variables are:

X(09) .799 X(01) .246

The correlation between independent variables is: .015.

ANOVA Table

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Due to regression | 2 | 826.081 | 413.041 | 28.135 |
| Residual | 25 | 367.020 | 14.681 | |
| Total | 27 | 1193.101 | | |

Since $F_{0.005}$ with 2/25 is 6.60, the regression is deemed significant at the 0.005 level.

Distance to live crown base (version 2), Y(13), ft.:

$\hat{Y} = 2.74312 + 0.44047\ X(09)$

| Variable | Description | Range | "t" value | Level of significance |
|---|---|---|---|---|
| Y(13) | Distance to live crown base (ft.) | 6.3-30.8 | | |
| X(09) | Live stem height (ft.) | 11.9-55.8 | 6.765 | 0.001 |

Simple linear correlation coefficient between Y(13) and X(09) is: .799.

ANOVA Table

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Due to regression | 1 | 760.868 | 760.868 | 45.768 |
| Residual | 26 | 432.233 | 16.624 | |
| Total | 27 | 1193.101 | | |

Since $F_{0.005}$ with 1/26 df is 9.41, the regression is deemed significant at the 0.005 level.

Live Crown Length, ft:

$\hat{Y} = -4.94041 + 5.46079\ X(1) - 0.25054\ X\ (1)^2$

| Variable | Description | Range | "t" value | Level of significance |
|---|---|---|---|---|
| $\hat{Y}$ | Live crown length (ft.) | 5.5-32.8 | | |
| X(1) | Live stem D.B.H, (in.) | 1.9-10.6 | 12.813 | 0.001 |
| $X(1)^2$ | Live stem D.B.H. squared ($in.^2$) | -- | 2.684 | .015 |

Simple linear correlation between $\hat{Y}$ and X(1) is: .914.

ANOVA Table

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Due to regression | 2 | 1288.536 | 644.268 | 85.691 |
| Residual | 25 | 187.962 | 7.518 | |
| Total | 27 | 1476.498 | | |

Since $F_{0.005}$ with 2/25 df is 6.60, the regression is deemed significant at the 0.005 level.

Whortleberry loading, T/A:

$\hat{Y} = 0.06077 + 0.00180\ X(1)$

| Variable | Description | Range | "t" value | Level of significance |
|---|---|---|---|---|
| $\hat{Y}$ | Whortleberry loading (T/A) | 0.00048-1.80766 | | |
| X(1) | Plant height·Crown cover (in.·%) | 2.5-792.0 | 10.335 | 0.001 |

Simple linear correlation between $\hat{Y}$ and X(1) is: .786.

ANOVA Table

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Due to regression | 1 | 6.828 | 6.828 | 106.803 |
| Residual | 68 | 4.347 | 0.064 | |
| Total | 69 | 11.175 | | |

Since $F_{0.005}$ with 1/68 df is 5.76, the regression is deemed significant at the 0.005 level.

Kinnikinnick loading, T/A:

$\hat{Y} + -0.000134 + 0.002194\ X(1) + 0.000137\ X(1)^2$

| Variable | Description | Range | "t" value | Level of significance |
|---|---|---|---|---|
| $\hat{Y}$ | Kinnikinnick loading (T/A | 0.00024-1.16701 | | |
| X(1) | Crown cover (%) | 2.5-88.0 | 21.899 | 0.001 |
| X(2) | Crown cover (%) squared | -- | 7.527 | .001 |

Simple linear correlation coefficient between $\hat{Y}$ and X(1) is: .857.

ANOVA Table

| Source of variation | df | SS | MS | F |
|---|---|---|---|---|
| Due to regression | 2 | 3.918 | 1.959 | 268.104 |
| Residual | 117 | 0.855 | 0.007 | |
| Total | 119 | 4.773 | | |

Since $F_{0.005}$ with 2/117 df is 5.56, the regression is deemed significant at the 0.005 level.